SEWAGE AND INDUSTRIAL WASTES

(Formerly Sewage Works Journal)

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

Special Features

Detergents in Sewage—Sperry

Hydrogen Sulfide Corrosion—Parker

Industrial Sewage Service Charges—Schroepfer

Phenol Determination—Dannis

DECEMBER, 1951—VOL. 23, No. 12

Make Plans to Attend

SILVER ANNIVERSARY MEETING

OF THE

FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

IN CONJUNCTION WITH

NEW YORK SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

HOTEL STATLER
NEW YORK CITY

October 6-9, 1952

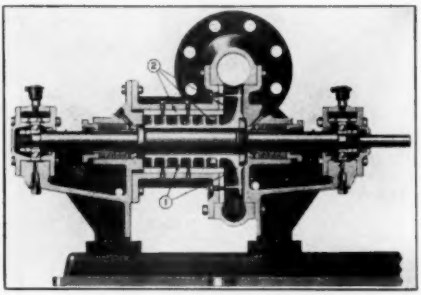
FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS
325 ILLINOIS BUILDING CHAMPAIGN, ILLINOIS

Chicago Pumps for Sewage and Sludge

SCRU-PELLER SLUDGE PUMPS

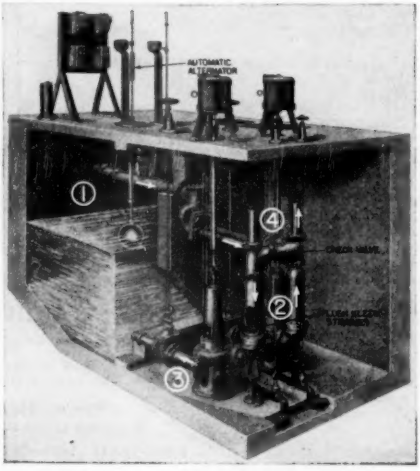
The Scru-Peller Pump was specifically designed to handle sludge. Coarse stringy material is cut and cannot wrap or bind the impellers.

1. **SCREW and IMPELLER** are keyed on the shaft and held firmly against a shoulder on the shaft by a nut. The screw has two flights; and the impeller has two blades. Each flight in the conveyor connects directly with its own blade of the impeller.
2. **CUTTING EDGES.** There are four stellited cutting bars and a shear ring in the screw housing. There are four more cutting bars in the pump casing. The stellited edges of the screw and the edges of the impeller blades act against the cutting bars and shear ring, completely chopping all coarse solid material into small pieces that cannot clog or slow the pump.



FLUSH-KLEEN EJECTORS

FLUSH KLEEN pumps provide automatic, trouble-free service in sewage lift-stations. They require no manual attention except periodic lubrication and inspection. No labor is required for disassembling and cleaning clogged pumps. FLUSH KLEENS are absolutely clog proof. The impellers handle nothing but strained sewage, minimizing wear and maintaining pump balance. They are the only absolutely clog proof sewage pump. The FLUSH KLEEN will pump anything that will pass through the pipe regardless of type or quantity of material.



FILLING WET WELL

1. Sewage flows through inlet pipe.
2. Coarse matter is retained on strainer.
3. Strained sewage flows through idle pump to wet well.

PUMPING

3. Strained sewage is pumped from wet well.
2. Coarse matter is backwashed from strainer.
4. Special check valve closes; sewage and coarse matter are pumped to sewers.

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SEWAGE AND INDUSTRIAL WASTES

REG. U. S. PAT. OFF.

A monthly Journal devoted to the advancement of fundamental and practical knowledge concerning the nature, collection, treatment and disposal of sewage and industrial wastes, and the design, construction, operation and management of such works.

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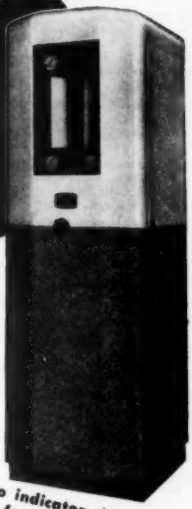

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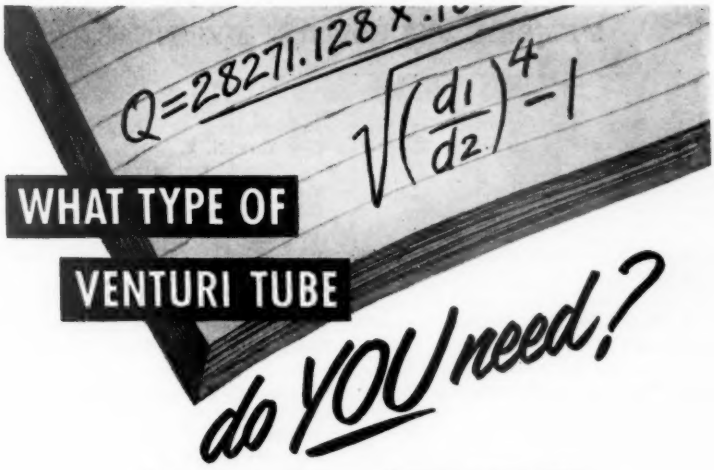

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1. Steel plate tube with cast iron throat section for measurement of clear water, air or gases.

2. Cast iron Venturi Tube with hand holes and cleaning valves at main and throat sections, for municipal sewage and trade wastes.

3. Cast iron Venturi Tube with flat invert and single cleaning valve at main and throat sections. Specifically used for sludge.

4. Cast steel or cast iron Venturi for hot or cold water and adaptable for boiler feed high pressure service.

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These tubes come in many sizes and different designs, some of which are pictured above. This means there's a particular tube to fit specific needs.

Write, stating your Venturi Tube requirements, to Simplex Valve & Meter Company, Dept. 12, 6719 Upland Street, Philadelphia 42, Pennsylvania.

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VALVE AND METER COMPANY

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Association	*Place*	*Time*
New York Sewage and Industrial Wastes Association	Hotel Statler, New York, N. Y.	Jan. 17–18, 1952
Texas Water and Sewage Works Association	Texas A. & M., College Station, Texas	March 9–13, 1952
New Jersey Sewage and Industrial Wastes Association	Hotel Traymore Atlantic City, N. J.	March 12–14, 1952
Arizona Sewage and Water Works Association	Maricopa Inn, Mesa, Ariz.	April 3–5, 1952
Arkansas Water and Sewage Conference	Engineering Building, University of Arkansas, Fayetteville, Ark.	April 7–9, 1952
Montana Sewage and Industrial Wastes Association	Northern Hotel, Billings, Mont.	April 10, 1952
South Carolina Water and Sewage Works Association	Clemson College Spartansburg, S. C.	April 10–12, 1952
Virginia Industrial Wastes and Sewage Works Association	Hotel Roanoke, Roanoke, Va.	May 12–13, 1952
Ohio Sewage and Industrial Wastes Treatment Conference	Commodore-Perry Hotel Toledo, Ohio	May 21–23, 1952
Alabama Water and Sewage Association	Pitts Hotel Auburn, Alabama	June 6, 1952
Pennsylvania Sewage and Industrial Wastes Association	Pennsylvania State College, State College, Pa.	Aug. 27–29, 1952
Iowa Sewage Works Association	Grinnell College Grinnell, Iowa	Sept. 9–11, 1952
Rocky Mountain Sewage Works Association	Frontier Hotel Cheyenne, Wyo.	Sept. 15, 1952

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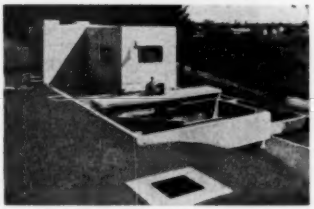
October 6–9, 1952

Ideal for small communities, isolated institutions, outlying plants

YEOMANS SEWAGE TREATMENT PLANTS

—Activated Sludge Process
or Biological Trickling Filter

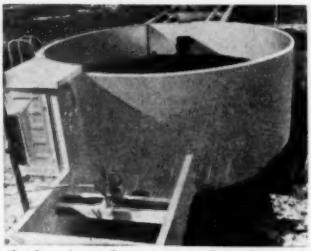


THE "PACKAGE" AERIFIER

Many small communities and outlying institutions, compelled to purify wastes but lacking an ample supply of diluting water, have found in the Yeomans "Package" Aerifier an ideal answer to a critical problem.

Compact, exceedingly efficient in purification, unique for low construction and operation costs, this activated sludge plant provides aeration and final sedimentation in a single concrete unit. Operation is as simple as possible, with supervision limited to routine check-up. Every installation includes final adjustment, initial tested operation, thorough training of operators and continuing counsel from Yeomans engineers.

"WATER-WHEEL" DISTRIBUTOR



Operating in conjunction with a primary sedimentation tank, the Yeomans "Water-Wheel" Distributor applies settled sewage to a trickling filter—with unfailing dependability. Sewage flows into the rotating trough, and is spread evenly on the filter bed through V-notches and spreader plates. The trough is actuated by a water-wheel and bevel gearing. Filter beds range from 5-foot to 25-foot diameters; and the entire area is effective for treatment. Continuous positive distribution is assured at all rates of flow—which does away with the need for dosing chambers and siphons. There is none of the clogging and cleaning of spray nozzles often required with reaction distributors; and elimination of accessories saves as much as the entire cost of the complete Water-Wheel installation. Maintenance is extremely simple. Numerous Water-Wheel plants—small communities, hospitals, airports, industrial plants—provide impressive proof of this unit's extraordinary efficiency.

Helpful engineering data on these Yeomans plants will be sent promptly upon request—no obligation.

YEOMANS PUMPS FOR YEOMAN SERVICE

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PUMPS FOR BUILDINGS, MUNICIPALITIES, INDUSTRIAL APPLICATIONS—and a complete line of Sewage and Waste Treatment Equipment

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Please send information as follows:

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☐ Yeomans "Package" Aerifier

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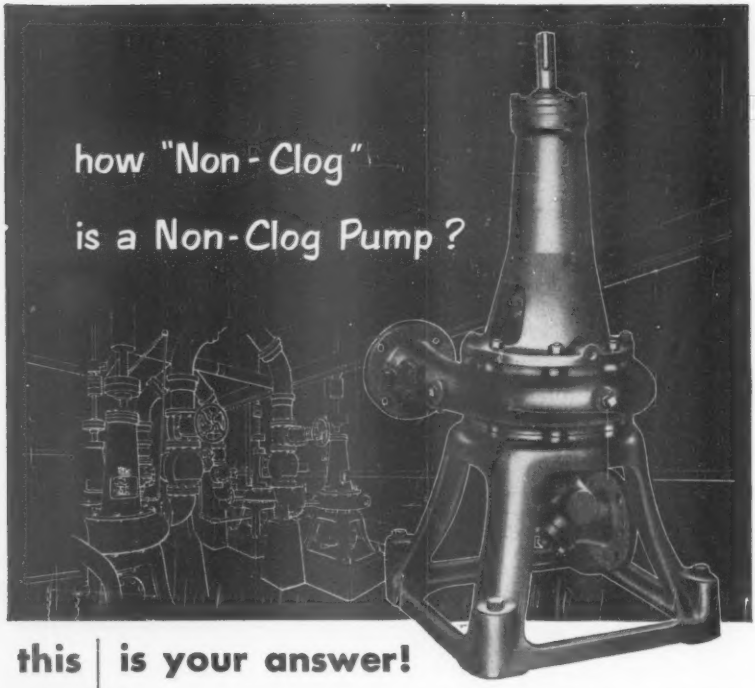
Address .....

City ..... State .....



this is your answer!

Any sewage and trash pump can be clogged! But the Fairbanks-Morse *Bladeless* Impeller Pump is up to 25 times more "non-clog" than any other pump. WHY?

The Fairbanks-Morse Impeller has no blades! It's a "whirling tube" with no blades or projections to catch and hold trash. The Fairbanks-Morse Bladeless Impeller Pump rarely has to be dismantled to clear "clogged impellers." With previous pumps, they had to be dismantled as often as twice daily.

For a specific solids size, the Bladeless Impeller Pump delivers approximately 50% of the capacity of conventional sewage pumps. Thus, you do not flood filter beds in periods of low flow. This reduced capacity also permits use of smaller driving motors.

Why not have your Fairbanks-Morse Pump Distributor or Local Branch Office give you the whole story? Or, if you prefer, write Fairbanks, Morse & Co., Chicago 5, Ill.

FAIRBANKS-MORSE,
a name worth remembering

PUMPS • SCALES • ELECTRIC MOTORS • GENERATORS • LIGHT PLANTS • DIESEL, DUAL FUEL AND GASOLINE ENGINES • MAGNETOS

Looking for efficient, LOW-COST SCREENINGS REMOVAL?

Immediate, overwhelming acceptance proves new LINK-BELT Thru-Clean Bar Screen the answer for handling screenings from sewage and industrial wastes

YES, 36 new Thru-Clean Bar Screens were sold in the 12 months following Link-Belt's initial announcement! Take a look at the partial list of installations and the consulting sanitary engineers who were responsible for them.

Then look at the advanced engineering illustrated by the photos below. They suggest how this new Link-Belt development can solve the problem of removing screenings from sewage or industrial wastes in your plant.

You can get the complete story by calling your nearest Link-Belt office. Or write for Folder No. 2327.

A FEW USERS OF THRU-CLEAN BAR SCREENS

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LINK-BELT

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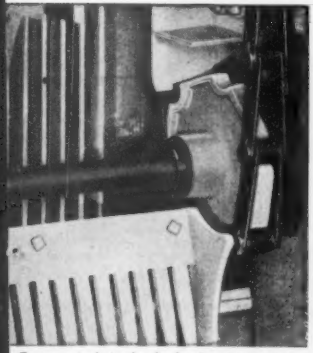
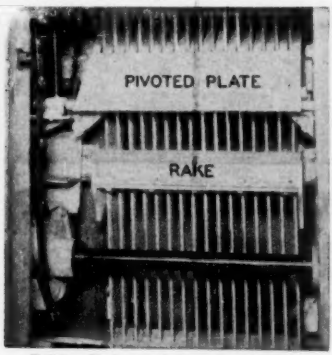
LINK-BELT COMPANY: Philadelphia 40, Chicago 9, Indianapolis 6, Atlanta, Houston 1, Minneapolis 5, San Francisco 24, Los Angeles 33, Seattle 4, Toronto 8, Springs (South Africa). Offices in principle cities. 12,310-A

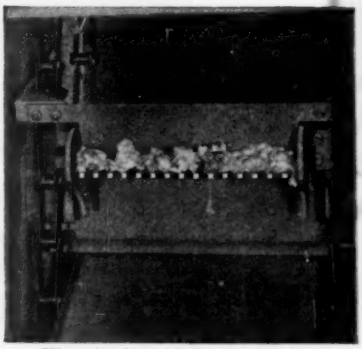
How rakes automatically clean bars "from the back"



Segmented steel rake is about to start its low-friction vertical movement. Entering from downstream side (*shown*), its forward and upward force precludes jamming or clogging. Travel starts at lowest point of channel, catches all solids retained by screen.



Cold-rolled steel bars, uniformly spaced, form screen. They are rigidly fixed at bottom of channel, extend only 6 in. beyond pivoted plate immediately above high water level. Simple, rugged construction minimizes maintenance. Low speed cuts power consumption.



Hinged wiper blade thoroughly cleans rake fingers, deposits screenings in trough for removal to shredder, disposal can or incinerator. Note the heavy, long-pitch Link-Belt chains, selected for trouble-free long life and assurance of proper travel for rakes.

Designs from engineers' notebooks

Weir with EVERDUR plate

This weir, specified by John J. Baffa, Consulting Engineer, New York, is designed to assure sustained and accurate water-level control. This, in turn, requires that the crest of the plate be capable of retaining a sharp edge against corrosion and erosion.

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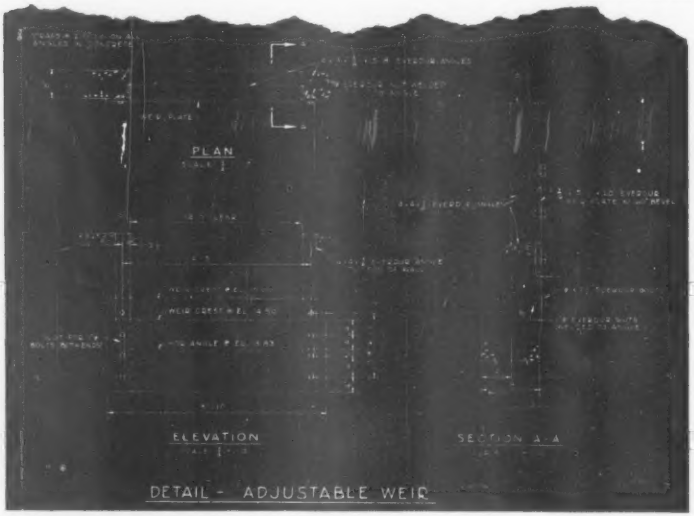

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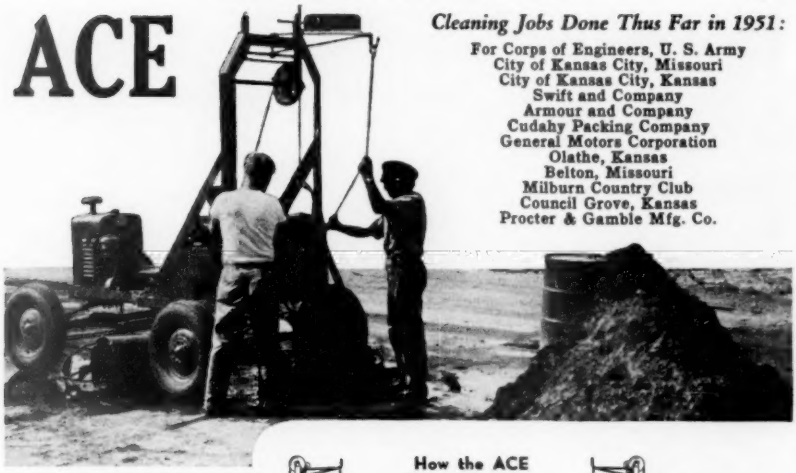

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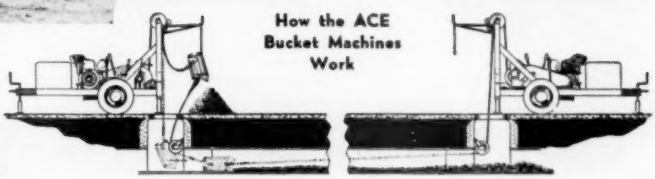

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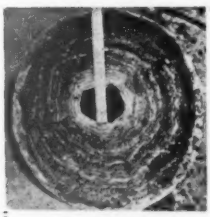

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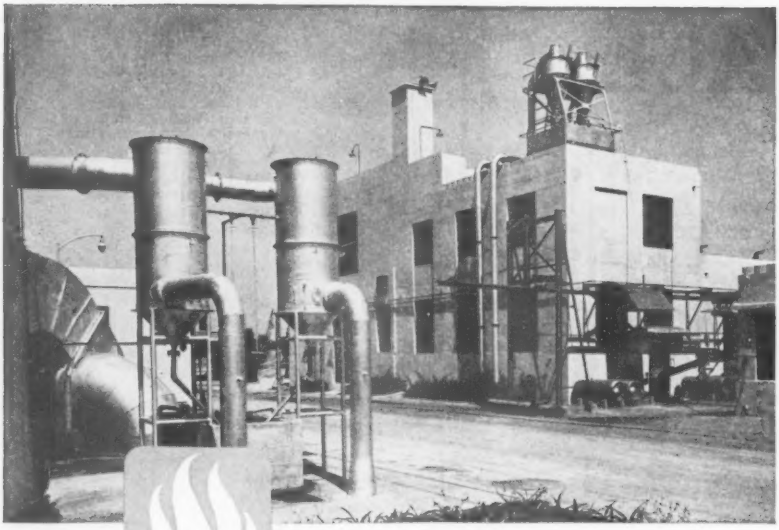

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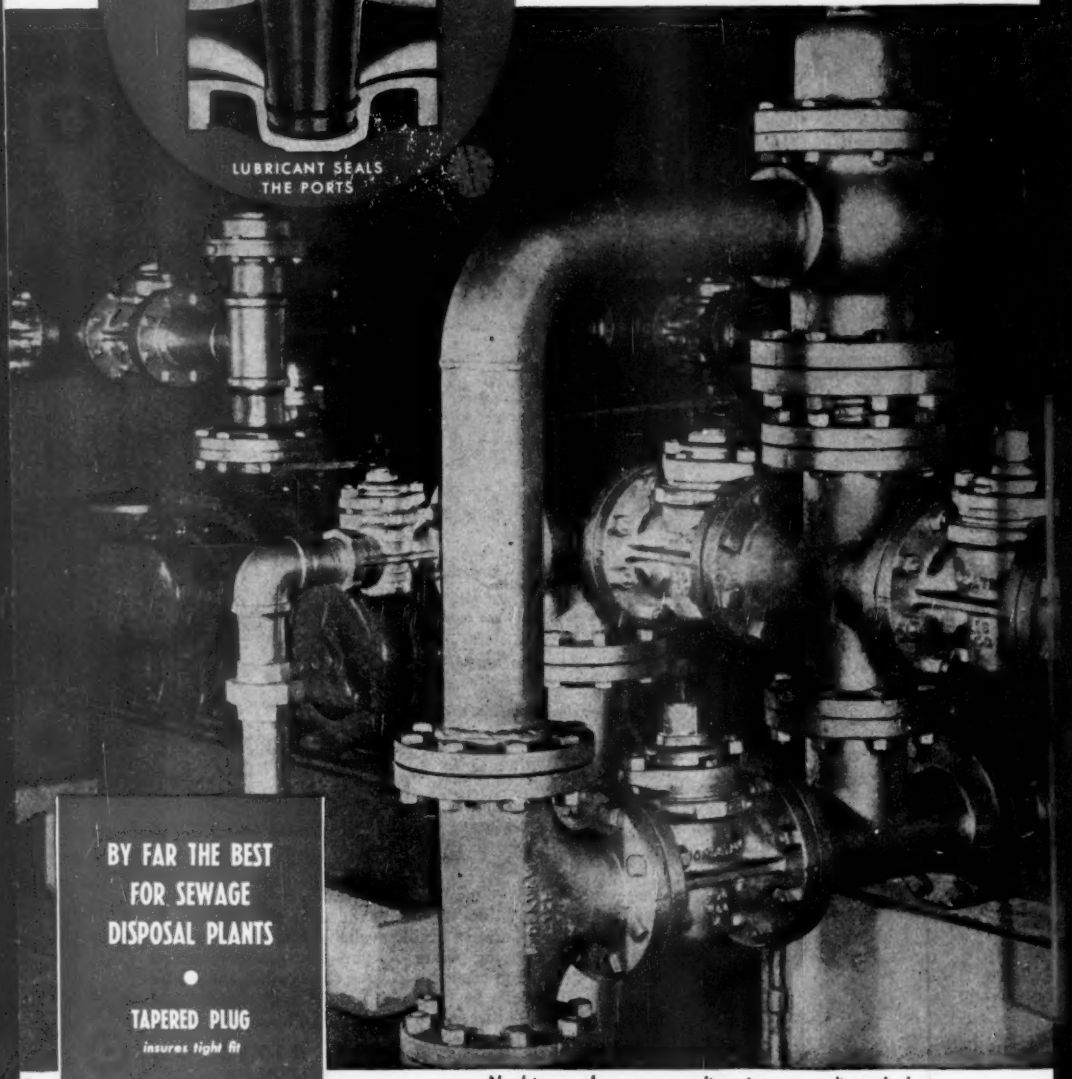

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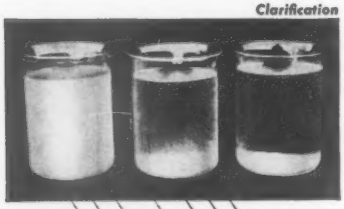

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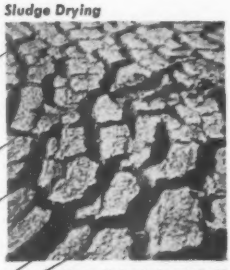

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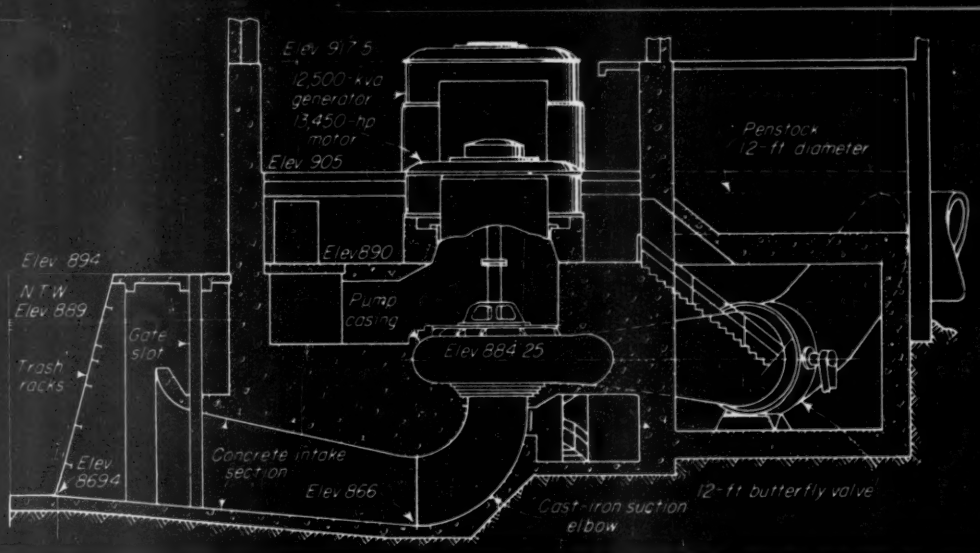

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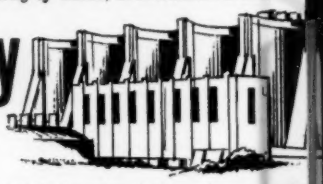

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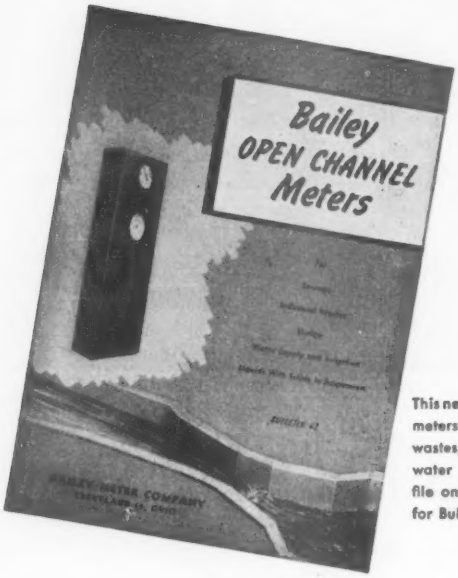

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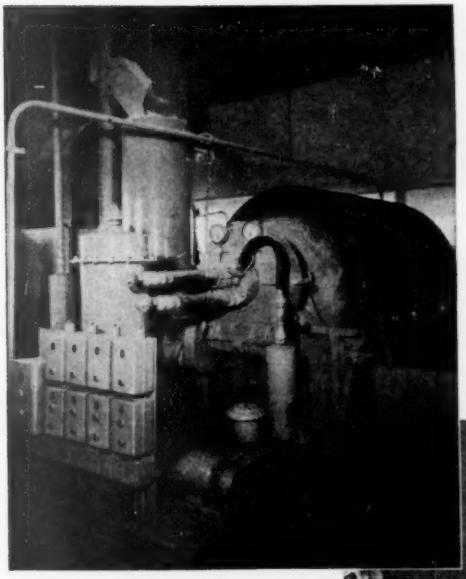

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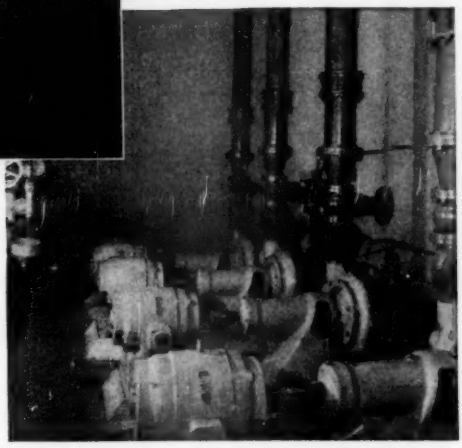

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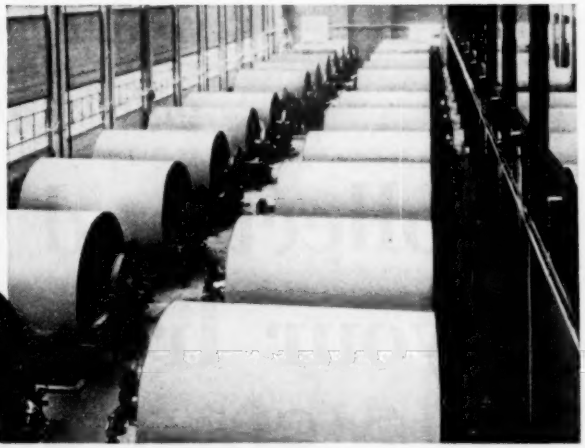

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SEWAGE AND INDUSTRIAL WASTES

Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 23 **DECEMBER, 1951** **Number 12**

Contents

Sewage Works

Detergents and Their Influence on Sewage Treatment. By Walter A. Sperry 1469

Mechanics of Corrosion of Concrete Sewers by Hydrogen Sulfide. By C. D. Parker 1477

Progress of Purification During the Starting of a Trickling Filter. By G. R. Grantham and J. C. Seeger, Jr. 1486

Industrial Wastes

Determination of Fair Sewage Service Charges for Industrial Wastes. By George J. Schroepfer 1493

Determination of Phenols by the Aminoantipyrine Method. By Michael Dannis .. 1516

Sedimentation and Flocculation Equipment for Treatment of Industrial Wastes. By J. H. Bass and R. R. Evans 1523

Treatment of Board Mill Waste at River Raisin Paper Company, Monroe, Mich. By M. F. Knack 1533

Activated Sludge Treatment of Milk Wastes. By Paul M. Thayer 1537

Cannery Waste Treatment and Disposal. By C. W. Templeton 1540

Studies of Biochemical Oxidation by Direct Methods. II. Effect of Certain Environmental Factors on the Biochemical Oxidation of Wastes. By H. Heukelekian and I. Gellman 1546

The Operator's Corner

Get in the Scrap! 1564

Winter Maintenance. By D. L. McLean 1565

Effects of Chemical Industry Wastes in Niagara Falls, N. Y., Sewage Treatment Plant. By Edward J. Smith 1567

The Daily Log, Plainfield (N. J.) Joint Meeting. By Andrew Palmer 1571

Phenol Wastes Upset Digesters at Hartford, Conn. By George Lebetkin 1573

Tips and Quips 1575

Reviews and Abstracts 1579

Author Index iii

Subject Index viii

Geographical Index xxiv

Proceedings of Member Associations

Georgia Water and Sewage Association 484a

Barbara B. Jacobson and Marjorie A. Portlock, *Editorial Assistants*

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Sewage Works

DETERGENTS AND THEIR INFLUENCE ON SEWAGE TREATMENT *

By Walter A. Sperry

Superintendent, Aurora Sanitary District, Aurora, Ill.

The word "detergent" is a general term derived from the Latin word *detergere*, meaning "to wipe off or cleanse." It applies generally to all cleansing agents. In this paper, however, it refers only to the modern group of synthetic detergents, as contrasted with soaps formed by the saponification of vegetable or animal fats, and their possible effects on sewage treatment.

The first synthetic detergent appeared about 1860. It was a sulfonated castor oil and was a first attempt to overcome the deficiencies of soap when used with hard water. Since then, the quantity of synthetic detergents produced and the variety available have so increased that whereas the production of soap from 1935 to 1950 averaged 2,675,000,000 lb. per year, with a range of 2,287,000,000 lb. (1930) to 3,303,000,000 lb. (1944), synthetic detergent production increased steadily from 44,900,000 lb. in 1935 to 1,070,000,000 lb. in 1950. A further increase in 1951 of 50 per cent (to 1,500,000,000 lb.) was predicted by *Soap and Chemicals* (April, 1951). The only check to even greater production appears to be insufficient manufacturing facilities and raw materials.

No attempt is made in this paper to describe the many types of synthetic detergents or discuss their properties and special applications. These matters have been adequately covered elsewhere. However, the following general group classifications are given:

1. Cationic compounds—Mostly quarternary ammonium compounds, such as Raccal and Diaperene, used for baby diaper washing. Cationic types tend to inhibit bacterial growth.
2. Anionic compounds—Usually fatty alcohol sulfates or sodium alkyl aryl sulfonates, such as Swirl, Dreft, Vel, Fab, Tide, and the like, much used about the house and good for grease removal. These compounds do not tend to affect bacterial growth.
3. Nonionic compounds—Derived from mineral oils, such as Glim, Igepal, or All.

Properties Affecting Sewage Treatment Processes

As the primary purpose of this discussion is to present data taken from sewage treatment plant records that tend to show the alleged effects of synthetic detergents, otherwise known as "surface tension reducing" or "wetting" agents, it may be well to list some of the properties ascribed to these agents that would affect sewage treatment processes.

These agents do not cause the "curdy" precipitates that soap does with hard water. Therefore, they are not wasted, as is soap, when used in hard water. They are used more abundantly in hard-water regions than in soft-water regions. Sewage plants in soft-water regions would, therefore, be

* Presented at 1951 Annual Meeting, Michigan Sewage and Industrial Wastes Assn.; Grand Rapids, Mich.; June 4–6, 1951.

less affected by any adverse properties of these agents. Due to their electrical properties and their non-reaction with hard water, suspended solids formation in raw sewage is reduced and suspended solids removal by primary tanks is diminished.

Due to their composition, as compared with soaps, the 5-day B.O.D. of sewage liquors tends to be reduced in proportion to the amount of detergents present. The process of digestion of sludges in digestion tanks is not affected, but plant operating data seem to indicate that the volume of gas to be expected is diminished. Due to their electrical properties, grease tends to be emulsified and carried over from the primary tanks to secondary processes. Synthetic detergents cause annoying nuisance factors in the form of violent frothing in those plants that employ mechanical types of activated sludge for secondary treatment.

The presence of cationic types of detergents (such as Diaperene, a quarternary ammonia type) tends to inhibit or check bacterial growth. In the recently appearing laundries specializing in baby diaper washing, this type of detergent is used largely for its partial sterilizing effect to check skin rashes. Its use is spreading to homes with new babies, and Diaperene is regularly on sale in tablet form at drug stores.

The presence of detergents in the raw water supply, in concentrations as low as 1.0 p.p.m., has been claimed (1) to cause an increase in the amount of coagulant necessary for the proper treatment of the water. Such effects would also be present in sewage plants using a chemical precipitation process.

Due to the varying types of detergents, their complex reactions, and their interaction on the varied contents of sewage liquors, no known tests have yet been devised for determining the amounts of detergents that may be present in a given raw sewage. One qualitative test states that if the pH of the liquor is reduced to 3.0 and the liquor is well-shaken, detergents are present if foam develops.

With these brief statements as a background, there are presented some plant operating data taken from the Aurora Sanitary District records, which seem to show detergent interference with plant performance.

Use of Detergents in Aurora, Ill.

An estimate of the probable use of detergents in the Aurora, Ill., area is based on the Brand Preference Study, whose source and authority are given in Table I, which includes a similar study for the sister cities of Rockford and Elgin, Ill. Table I shows an increasing preference for detergents for fabric and dish washing for the years 1947–1950, inclusive. Of the families in the area, 8,888 (59.8 per cent) preferred detergents over soap for fabric washing in 1950. Likewise, 11,474 (77.2 per cent) of the families preferred detergents over soap for dish washing in 1950.

TABLE I.—Brand Preference Data (Abbreviated)[1]—Courtesy, *The Aurora Beacon News*

City	Detergent Preference (%)				Families 1950	Water Hardness (p.p.m.)
	1947	1948	1949	1950		
(a) For Fabrics						
Aurora, Ill.	43.3	48.0	57.2	59.8	8,888	370
Rockford, Ill.	30.9	33.2	49.8	52.6	19,241	370
Elgin, Ill.	45.1	31.3	32.1	39.8	4,148	85
(b) For Dish Washing						
Aurora, Ill.	57.6	65.7	71.0	77.2	11,474	370
Rockford, Ill.	48.1	54.6	66.9	74.8	27,471	370
Elgin, Ill.	43.0	46.7	42.9	54.0	5,628	85

[1] Data taken from the 1950 Illinois Consumer Analysis, published by the Illinois Daily Newspaper Markets, Inc., Springfield, Ill. Data compiled by Illinois Research and Survey, Springfield, Ill. The accuracy claimed by the Survey is 0.1 per cent of error. The whole table presents the preference of 7 popular brands of soap and soap powders and 6 popular brands of detergents to a total of 100 per cent. Only the combined detergent preference is given here.

Aurora is supplied with water from deep wells in a limestone region. The unsoftened water supply averages 370 p.p.m. of total hardness; therefore, the city is in a hard-water region.

A canvas of the grocery stores indicated that the ratio of detergent sales to soap sales averaged 75 per cent *versus* 25 per cent. Two stores indicated 85 to 90 per cent in favor of detergents. The wholesale grocery company generally confirmed these figures. A sampling of housewives as to their use of detergents leveled off to one box of detergent per week for dish washing and one-half box per week for clothes washing.

Each of the three large hospitals used soap in the laundry and tri-sodium phosphate for the kitchens, but wholly on the basis of less cost than for detergents. Two of the four laundries used soap, but one used detergents (Orvus) at the rate of 45 lb. per week, and one used detergents (4 lb. per week) in the dry cleaning department. The three dairy companies jointly accounted for 50 lb. of detergents used per week.

On the basis of 1 lb. per package all this sums up to:

231,000 lb. per year for clothes (8,888 × 26 lb.)
597,000 lb. per year for dishes (11,474 × 52 lb.)
2,500 lb. per year for laundries
2,600 lb. per year for dairies

833,100 lb. per year

This gives a total of 833,100 lb. per year or, in round numbers, 2,300 lb. per day. On this basis, a concentration of 45 p.p.m. of detergents exists in Aurora's average dry-weather flow of 6.14 m.g.d.*

In considering the reasonableness of the foregoing estimates, it is further pointed out that *Soap and Chemicals* (Mar., 1951) carried a tabulation of the use of detergents in nine large and scattered cities for the years 1947–1950. These figures show that the use of detergents for fabric cleaning has increased 2.9 per cent per year since 1947 and stood at 37.3 per cent in 1950. For dish washing, the increase in detergent use was 6.8 per cent per year since 1947 and stood at 56.8 per cent in 1950. These figures, however, were for country-wide use, including soft-water areas, whereas the Aurora figures are for a specific study in a hard-water region. Also, *Chemical Week* (May, 1951) tabulates 18 widely diversified industries, ranging from drugs and cosmetics to metal-working industries, that are finding uses for surface-active agents. This statement would account for additional discharges of detergents to sewers that cannot readily be estimated.

Effects at Aurora

For the past four or five years sludge gas production at Aurora so diminished as to cause some concern. Aurora's experience seemed to be confirmed by the experience of other plants, but the cause was generally obscure. At the end of 1950 a study was made of all the factors having to do with gas production since 1931. It should be noted that, in contrast with tables to follow, this study was based on annual averages and included both the wet- and dry-weather flow months. The results of this study are presented in Table II, which shows a general decline in gas production, suspended solids, and pounds of primary sludge available

* All data in this paper referring to the probable use of detergents in Aurora are based on packaged material. Mr. Leon Kraus of Peoria, who studied this paper, reports that *Consumers Research Bulletin* (Aug., 1950, p. 21, and Mar., 1951, p. 21) states that the active agents in packaged detergents averaged 27 per cent and in liquid detergents 53 per cent. It is believed that the quantity of liquid detergent used in Aurora is not great. Based on packaged detergents at 27 per cent, the use of active agent detergents in Aurora would be 620 lb. per day. This is equivalent to 12.2 p.p.m. of active detergent, as against 13.4 p.p.m. as estimated by Kraus for Peoria. It is believed that 10 p.p.m. of active detergent would have deleterious effects on sewage treatment.

that are inconsistent with Aurora's population increase and sewage flow. The break began in 1946, which was about the time when detergents began to be generally popular. Later, in 1949–50, two additional factors loomed up, as the routine tests were recorded, that seemed to demand an explanation. The settleable solids (1-hr. Imhoff cone test) seemed low and the free ammonia in the effluent was distinctly high. Simultaneously, the character of the slimes on the filter stone changed, in that the knots of *Lumbiculus*, always heretofore abundant, disappeared. No explanation of this phenomenon was at hand. Tests for cyanides proved negative and Aurora has no plating or copper-working industries sufficient to account for enough copper or chromium to have caused such an effect.

A further study of the records based upon dry-weather flow months only, to get equal concentration and uniform raw sewage quality, was made for the years 1938 to 1950, inclusive. The results of this study are presented in Tables III and IV. Table III records the settleable solids, suspended solids, 5-day B.O.D., and free ammonia for the raw, clarified, and filtered sewage liquors. Table IV records the gas production history. Both tables show a distinct break in the records between the years 1948 and 1949. Also, it should be noted that, due to including only dry-weather flow months, there is a very satisfactory consistency of all values shown for the two periods contrasted.

In Table I it will be observed that the preference for detergents in Aurora noticeably increased in 1949 and 1950. As shown in the summary comparisons of Tables III and IV, settleable solids, suspended solids, 5-day B.O.D., and gas

TABLE II.—Factors in Gas Production at Aurora, Ill., Sewage Treatment Plant[1]

Year	Pop. (×1,000)	Rainfall (in.)	Sewage Flow (m.g.d.)	Susp. Sol., Raw Sewage (p.p.m.)	Pri-Sec. Sludge (lb./day)	Vol. in Pri-Sec. Sl. (lb./day)	Vol. (%)		Gas			Dig. Temp. (° F.)
							Pri. Sl.	Sec. Sl.	Total (10^6 cu. ft.)	Per Lb. Vol. Added (cu. ft.)	Per Capita (cu. ft.)	
1931	43.0	35.7	5.8	167	3500	2470	70.6	—	10.6	11.8	0.70	93
1932	47.0	32.03	7.2	140	4000	2700	67.5	—	12.3	12.5	0.70	88
1933	47.0	30.50	6.6	130	3500	2350	67.0	—	10.3	12.0	0.60	84
1934	47.0	26.90	5.6	184	4080	2940	72.1	—	13.3	12.5	0.80	89
1935	47.0	41.04	7.2	148	4220	2820	67.0	—	11.6	11.3	0.70	85
1936	47.0	31.90	7.1	149	5440	3900	71.6	—	16.7	11.7	1.00	85
1937	49.0	28.3	6.3	168	6340	4840	66.6	58.2	18.1	10.2	1.00	84
1938	49.0	37.6	7.2	161	6460	4790	63.0	54.7	17.3	9.9	1.00	87
1939	49.0	28.5	7.0	187	6220	4830	69.8	59.6	18.5	10.4	1.00	89
1940	49.0	36.6	6.8	189	6400	5280	71.3	61.9	20.2	10.4	1.13	90
1941	49.0	41.3	8.4	167	6610	5060	69.5	60.3	17.8	9.6	1.00	87
1942	49.0	34.8	7.7	175	7500	6160	72.5	62.6	19.6	8.8	1.10	83
1943	51.0	30.4	7.8	174	6750	5800	73.1	62.4	17.8	8.4	0.95	85
1944	51.0	25.1	6.6	188	7340	5955	74.3	63.3	19.2	8.7	1.03	87
1945	51.0	39.4	6.7	196	7400	6080	74.0	64.5	17.0	7.6	0.91	88
1946	54.0	26.9	6.2	231	8490	6780	73.1	62.8	18.1	7.3	0.92	84
1947	56.0	36.8	7.4	193	7920	6250	73.3	60.2	16.4	7.2	0.80	86
1948	56.0	33.3	7.0	211	7510	5770	69.8	53.1	19.3	9.2	0.94	89
1949	56.0	34.1	6.3	182	6360	5060	69.0	54.4	14.8	8.0	0.72	89
1950	57.2	36.2	7.3	179	8410	6220	68.6	56.4	10.9	4.8	0.52	81

[1] Single-stage digestion from 1931 to Aug. 1, 1936; two-stage digestion from Aug. 1, 1936 on. Secondary settling basins installed Jan. 1, 1937, increasing volume of sludge to digesters. Table based on annual totals or averages for each year.

TABLE III.—Study of Sewage Characteristics[1] for Dry-Weather Flow Months to Show Possible Effects of Detergents in Raw Sewage

Year	Mo. of Dry Flow	Flow (m.g.d.)	Sett. Sol., 1-Hr.			Susp. Solids					5-Day B.O.D.					Free Ammonia		
			Raw (c.c.)	Clar. (c.c.)	Rem. (%)	Raw (p.p.m.)	Clar. (p.p.m.)	Filt. (p.p.m.)	Rem. Clar. (%)	Rem. Filt. (%)	Raw (p.p.m.)	Clar. (p.p.m.)	Filt. (p.p.m.)	Rem. Clar. (%)	Rem. Filt. (%)	Raw (p.p.m.)	Filt. (p.p.m.)	Rem. (%)
1938	4	6.223	7.4	0.6	91.8	184	67	37	63.5	80.0	138	84	31	39.2	77.7	6.2	3.0	51.6
1939	5	5.939	7.7	0.7	90.7	209	78	45	62.6	78.5	163	94	22	42.3	82.2	7.3	1.1	85.0
1940	8	6.307	6.5	0.8	87.6	201	80	66	60.2	67.3	159	100	25	37.1	84.2	7.0	0.8	88.6
1942	2	6.457	6.4	0.5	92.1	191	78	43	59.2	77.6	150	79	23	47.3	84.4	7.9	1.2	84.7
1943	4	6.305	7.6	0.6	92.0	207	81	42	60.9	79.6	136	80	21	40.7	81.3	7.4	1.4	81.0
1944	8	5.652	7.8	0.6	92.4	203	78	42	61.6	79.3	140	84	24	40.0	82.7	7.8	1.3	83.2
1945	7	6.154	6.9	0.6	91.0	212	76	43	64.1	79.8	135	80	25	40.7	81.4	7.0	1.2	83.0
1946	11	6.040	9.8	1.2	87.8	237	85	49	64.0	79.3	150	87	27	42.0	81.8	8.2	1.5	81.6
1947	6	6.546	7.4	0.9	87.8	217	86	51	60.4	76.4	175	102	37	41.6	79.1	8.2	1.6	80.4
1948	7	6.277	6.7	0.7	89.4	232	91	58	60.7	74.9	153	91	25	40.4	83.5	8.8	2.5	71.6
Av.[2]	62[3]	6.190	7.4	0.7	90.5	209	80	47	61.6	77.5	150	88	26	41.4	82.7	7.6	1.5	80.3
1949	10	6.159	4.1	0.4	90.2	180	84	56	53.3	69.0	115	75	30	34.7	73.8	8.7	3.3	62.0
1950	5	5.985	4.7	0.7	85.2	217	89	62	59.0	71.3	157	107	42	31.8	73.4	11.2	4.8	57.2
Av.[4]	15[3]	6.072	4.4	0.5	88.4	198	86	59	56.5	70.1	136	91	36	33.2	73.6	9.9	4.0	59.6
Comp.[5]	—	—	−3.0	—	−2.1	−11	+6	+12	−5.1	−7.0	−14	+3	+10	−8.3	−9.1	+2.3	+2.5	−20.7

[1] Yearly average values.
[2] Average for 10 years.
[3] Total.
[4] Average for 2 years.
[5] Comparison of 1949–50 average with 1938–48 average.

TABLE IV.—Study of Gas Production[1] for Dry-Weather Flow Months to Show Possible Effects of Detergents in Raw Sewage

Year	Mo. of Dry Flow	Flow (m.g.d.)	Gas Prod. (cu. ft./day)	Dig. Temp. (° F.)	Primary Sludge		Sec. Sludge		Total Vol. to Dig. (lb.)	Gas Per Lb. V.M. (cu. ft.)
					(lb./day)	Vol. (%)	(lb./day)	Vol. (%)		
1938	4	6.223	55,030	85	7,300	70.7	740	60.4	5,590	9.8
1939	5	5.938	57,010	88	6,790	72.0	1,140	61.1	5,580	10.2
1940	8	6.307	55,040	88	6,360	72.4	1,180	63.0	5,230	10.5
1942	2	6.477	58,630	89	8,050	73.3	1,150	62.3	6,610	8.8
1943	4	6.305	56,510	89	7,680	75.6	1,190	63.7	6,560	8.6
1944	8	5.651	59,210	89	7,820	75.6	830	64.6	6,440	9.2
1945	7	6.154	51,370	89	7,890	74.2	790	65.2	6,360	8.0
1946	11	6.045	50,920	84	8,770	73.7	940	62.7	7,040	7.2
1947	6	6.546	52,800	86	8,280	75.6	670	61.3	6,680	7.9
1948	7	6.277	58,510	93	7,807	71.2	1,250	53.4	6,210	9.4
Av.[2]	62[3]	6.192	55,500	88	7,675	73.4	988	61.8	6,230	8.9
1949	10	6.159	40,800	89	6,390	68.7	1,360	54.8	5,110	8.0
1950	5	5.985	38,900	84	7,020	70.8	1,050	58.9	5,620	6.9
Av.[4]	15[3]	6.072	39,850	86	6,700	69.8	1,210	56.9	5,370	7.4
Comp.[5]	—	—	−15,600	−2	−975	−3.6	+222	−4.9	−860	−1.5

[1] Yearly average values.
[2] Average for 10 years.
[3] Total.
[4] Average for 2 years.
[5] Comparison of 1949–50 average with 1938–48 average.

production are all lower in the 1949–1950 period; the free ammonia was distinctly higher and, to date, the increase is completely unaccounted for. Any effort to interpret or explain the differences shown in the two periods compared seems to point to the influence of the known presence of synthetic detergents in the raw sewage.

With respect to the performance of the digesters, it has been stated that the process of digestion is not affected by the presence of detergents. The following data from Aurora experience confirms this:

Year	Vol. Matter (%)		Av. Gas Prod. (cu. ft./day)	Dig. Temp. (° F.)
	Prim. Sludge	Dig. Sludge		
1947	73.3	57.8	55,600	89
1948	69.8	46.3		
1949	69.0	44.3	39,850	86
1950	68.6	43.0		

With respect to the possible effects of the presence of cationic detergents, such as Diaperene, another puzzle is presented. For several years previous to World War II, careful bacterial and coliform tests were made on the sewage liquors at 9:30 A.M. and 1:30 P.M. each week. The average 24-hr., 37° C. count (agar) on the raw sewage for the years 1938–1940 was 3,300,000 per c.c. at 9:30 A.M. and 3,600,000 per c.c. at 1:30 P.M. Bacterial counts made on the raw sewage between June 6, 1949, and January 25, 1950, on grab samples on nine scattered days averaged 1,760,000 per c.c. The range was from 2,600,000 to 1,080,000 per c.c. The average flow for the counts made in the prewar period was 7.34 m.g.d.; for the nine days tested recently, 7.13 m.g.d.

A search of the Aurora records for grease and scum recovered, in cubic feet per day, for the two dry-weather flow periods studied gave no results.

Rockford and Elgin Records

After investigating the Aurora records, the treatment plants in the neighboring cities of Rockford and Elgin were visited for possibly similar results.

Rockford is a city of about 95,000 population, with a hard-water supply similar to that of Aurora. Its industries are more varied and include some that produce toxic wastes. The treatment plant is planned for primary treatment only. Recently, its primary settling tanks and digester systems were materially enlarged. Henry Reidesel, chief engineer, and Paul Carlson, operating chemist, were at once interested and made a study of their records on the same dry-weather flow basis as that made for Aurora. In fact, they had already had a similar suspicion that detergents might be affecting their treatment. The summary comparison from their study is given in Table V.

The city of Elgin has a population of about 44,000, with a softened water supply (85 p.p.m. total hardness). The sewage treatment plant has secondary treatment similar to that at Aurora. The primary side of the plant, however, is a combination of Imhoff tanks and separate sludge digestion tanks. Some of its industries discharge toxic wastes in the form of cyanides, copper, and chromium in quantities sufficient to affect the operation of the stone sprinkling filter beds. Floyd E. Johnson, district superintendent, cooperated in this study and prepared a similar dry-weather flow study of his record for this paper. The summary comparison of the Elgin data is given in Table VI.

TABLE V.—Summary Comparison of Operating Data for Rockford, Ill., Sewage Treatment Plant

Item	Period		Diff.
	1940–48 (83 mo.)	1949–50 (18 mo.)	
Av. dry-weather flow (m.g.d.)	13.64	16.15	
Settleable solids, 1-hr.:			
Raw (c.c.)	5.9	6.2	+ 0.3
Clarified (c.c.)	0.14	0.23	
Removed (%)	97.8	96.2	− 1.6
Susp. solids:			
Raw (p.p.m.)	223	188	−35
Clarified (p.p.m.)	73	70	− 3
Removed (%)	67.2	62.7	− 4.5
5-day B.O.D.:			
Raw (p.p.m.)	188	157	−31
Clarified (p.p.m.)	101	92	− 9
Removed (%)	46.2	41.3	− 4.9
Gas (cu. ft./day)	102,840	81,350	−21,490
Primary sludge (lb./day)	20,290	19,640	−650
Vol. (%)	71.6	70.6	− 1.0
Digester temp. (° F.)	81.5	78.0	− 3.5
Gas per lb. vol. (cu. ft.)	7.0	5.9	− 1.1

TABLE VI.—Summary Comparison of Operating Data for Elgin, Ill., Sewage Treatment Plant

Item	Period		Diff.
	1944–48 (43 mo.)	1949–50 (17 mo.)	
Av. dry-weather flow (m.g.d.)	4.14	4.27	
Settleable solids, 1-hr.:			
Raw (c.c.)	2.2	2.4	+ 0.2
Clarified (c.c.)	0.1	0.2	+ 0.1
Filtered (c.c.)	0.4	0.9	+ 0.5
Effluent (c.c.)	0.2	0.6	+ 0.4
Removed, clar. (%)	85.4	81.7	− 3.7
Removed, filt. (%)	81.7	62.4	−19.3
Removed, effl. (%)	90.8	75.0	−15.8
Susp. solids:			
Raw (p.p.m.)	159	150	− 9
Clarified (p.p.m.)	78	89	+11
Filtered (p.p.m.)	46	56	+10
Effluent (p.p.m.)	39	48	+ 9
Removed, clar. (%)	51.0	40.7	−10.3
Removed, filt. (%)	71.2	62.7	− 8.5
Removed, effl. (%)	75.5	66.9	− 8.6
5-day B.O.D.:			
Raw (p.p.m.)	156	181	+25
Clarified (p.p.m.)	121	136	+15
Filtered (p.p.m.)	51	66	+15
Effluent (p.p.m.)	45	61	+16
Removed, clar. (%)	22.4	24.8	+ 2.4
Removed, filt. (%)	67.2	63.4	− 3.8
Removed, effl. (%)	71.2	66.2	− 5.0
Gas (cu. ft./day)	14,100	14,900	+800
Primary sludge (lb./day)	1,810	1,830	+20
Vol. (%)	77.1	76.7	− 0.4
Digester temp. (° F.)	93.0	95.0	+ 2.0
Gas per lb. vol. (cu. ft.)	10.0	10.6	+ 0.6

Summary

It is believed that the data presented herein indicate a new approach to the problem of detergent effect on sewage treatment. It is based on an analysis of plant records, which seem to show definite trends toward detergent influence. It also presents an analysis of the use of detergents in a hard-water community, which indicates increasing preference over soap in a definite upward trend.

Although only two years are shown as indicating possible detergent effects,

these two years definitely tie in with the increasing popularity of detergents in 1949–50. Obviously, if the records for the next two or three years follow suit, the conclusions drawn will be better confirmed.

The Aurora data show reduced removals of suspended solids and 5-day B.O.D. in the primary tank and increased loads passed to the secondary units.

The data also indicate decreased gas production with normal digester operation, consistent with the findings of Rudolfs and others. The problem of the role that temperature *versus* gas production plays in the digesters has been bothersome, although, as the data indicate, the average digester temperatures in the periods studied at Aurora were sufficiently close as to rule out temperature.

No explanation is offered of the free ammonia increase in the effluent in 1949–50. Also unexplainable are the lowered bacterial counts reported, except as showing the influence of detergents.

No experimental work was attempted during the preparation of this paper because of highly diluted flows resulting from winter and spring rains and ground-water leakage.

Despite the considerable care exercised to break down and prepare the Rockford records, they are not as consistent as the Aurora records, although they show general trends, especially in the matter of gas production. The Rockford records differ from those of Elgin and Aurora in that the records of the latter two cities show very uniform flow conditions and, therefore, uniform concentration for the two periods contrasted, whereas the rapid growth of Rockford caused a considerable variation in flow for the pre-detergent period (11.3 m.g.d. in 1940 to 16.4 m.g.d. in 1948), which may have masked detergent effects somewhat.

The Elgin records show the same uniform flows and concentrations as for Aurora. They include data for the effluent sewage as well. The Elgin data, however, are more contradictory and completely fail to show less gas production. This is undoubtedly due to the lesser use (by 20 per cent) of detergents because of the softened water supply. It is also interesting to note the effect of advertising in 1947 for fabric washing, followed by a partial return to soap in the succeeding years. For dish washing the gain for the four years was only 11 per cent, whereas the gain in the other two cities was 24 per cent.

Reference

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MECHANICS OF CORROSION OF CONCRETE SEWERS BY HYDROGEN SULFIDE*

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Although papers have been published from time to time dealing with various particular aspects of the problem of corrosion of concrete sewers by hydrogen sulfide, no comprehensive and up-to-date review of the subject as a whole is available.

This review and assessment of present knowledge of the whole problem is presented, therefore, primarily as a basis for a discussion on the necessity for further investigation. It also serves as a background for discussion concerning the fundamental reasons for the effectiveness of various remedial measures.

In its compilation, the published literature has been taken into account and the results of a considerable amount of unpublished work carried out in the laboratories of the Melbourne and Metropolitan Board of Works have been used.

Conditions for Corrosion

The most outstanding characteristic of this form of corrosion is the fact that it only occurs above the waterline. There is no attack below daily low-water level and the point of most intense attack is frequently observed just above daily high-water level.

Corrosion does not occur in sewers running completely full. For this type of corrosion to occur hydrogen sulfide (H_2S) must be present in the sewer air above the free water surface. Certain requirements regarding ventilation (or lack of ventilation) and sewer air humidity must also be met.

These points, together with the various detailed processes described later, are shown diagrammatically in Figure 1.

Products of Corrosion

The products of corrosion by hydrogen sulfide are characterized ultimately by a complete destruction of the strength of the concrete, which is reduced to a formless mass. In the early stages of corrosion the surface of the concrete sewer may develop a fairly dry incrustation of corrosion products, which later become more moist, and the surface eventually shows the complete disintegration already mentioned. Chemical analysis reveals a very high concentration of sulfate and the corrosion products are characterized by a progressive lowering of pH with intensification of corrosion. In the final stages of disintegration the pH is frequently less than 2.0.

Occurrence and Production of H_2S in Sewers

As previously stated, it is a primary requirement for corrosion that H_2S shall be present in the sewer air. For H_2S to be present in the sewer air it must arise from the sewage, where it may be present either through the discharge of trade wastes containing inorganic sulfides from such industries as tanneries and photographic processors or through the biological production of H_2S in the sewer itself.

H_2S may be produced biologically in

* Presented at a conference of Australian sewerage authorities; Melbourne; Nov. 28–30, 1950.

sewers from either or both of two different sources, as follows:

1. From compounds (such as cystine) containing organic sulfur formed from the hydrolysis of proteins, by the loss of the sulfhydryl group; that is,

$$\begin{matrix} NH_2 & & NH_2 \\ CH - CH_2 & CH_2 - CH & + H_2 + 4H_2O \\ COOH \quad S - S & COOH & \end{matrix}$$

$$\rightarrow 2H_2S + 2NH_3 + 2CH_3COOH + 2H\cdot COOH$$

$$\downarrow$$

$$2H_2 + 2CO_2$$

This is effected under anaerobic conditions by a large number of species of proteolytic bacteria in sewage, including *E. coli, Proteus vulgaris,* and *Pseudomonas pycocyanea.*

2. H_2S may also be produced by the bacteriological reduction of sulfates to sulfides by the anaerobic organism *Sporovibrio desulphuricans.* Organic compounds formed from the degradation of soap, cellulose, starch, and protein are oxidized while the sulfate is reduced; that is,

$$CH_3COOH + H_2SO_4 \rightarrow H_2S + 2CO_2 + 2H_2O$$

Both processes take place in the absence of oxygen, but the degree of anaerobiosis is greater (the oxidation reduction potential is lower) during sulfate reduction. It is, therefore, feasible, as pointed out by Eliassen, Heller, and Kisch (5), that H_2S production from organic sulfur compounds precedes its production from sulfates in sewage containing both sources of sulfur.

The organic sulfur compounds from which H_2S may arise may be present in concentrations of 1 to 2 p.p.m. (as sulfur) in domestic sewage and 5 to 10 p.p.m. in sewage containing a substantial proportion of industrial wastes. Some wastes from industries such as abattoirs, gut processing, or wool scour may contain 50 to 100 p.p.m.

The sulfates are present in the sewage almost entirely as inorganic sulfates and enter the system either as a soluble constituent of the water supply, in saline ground water infiltrating into the system, or through the use by industry of tidal or sea water which is subsequently discharged to the sewer. The organic matter responsible for the reduction of the sulfate is that normally present in sewage, but the presence of some industrial wastes may increase the supply.

H_2S generation in any particular sewer will, therefore, arise from either organic sulfur or sulfates, or from both, depending on the concentration of each present.

The exact site where H_2S generation occurs in the sewer is a subject which has been given considerable attention recently. Baumgartner (2) stated that H_2S production in sewers was increased by deposited silt. Pomeroy and Bowlus (9) stated that substantially the whole of the H_2S generation in sewers occurred in the slime layer which developed on the underwater surface of the pipe. Heukelekian (6) agreed with Pomeroy and Bowlus that H_2S generation does not occur in the flowing sewage, but differed from those authors in claiming that it occurred in deposited sludge at the bottom of the sewer.

Observations in Melbourne indicate that slime growths are present on the underwater surface of both gravity sewers and rising (force) mains. With gravity sewers a considerable slime development is formed between daily high- and low-water level. In general, environmental conditions, bacterial count, and oxidation reduction potential are far more suitable for H_2S generation in these slimes than in the flowing sewage, and slimes cultured in the

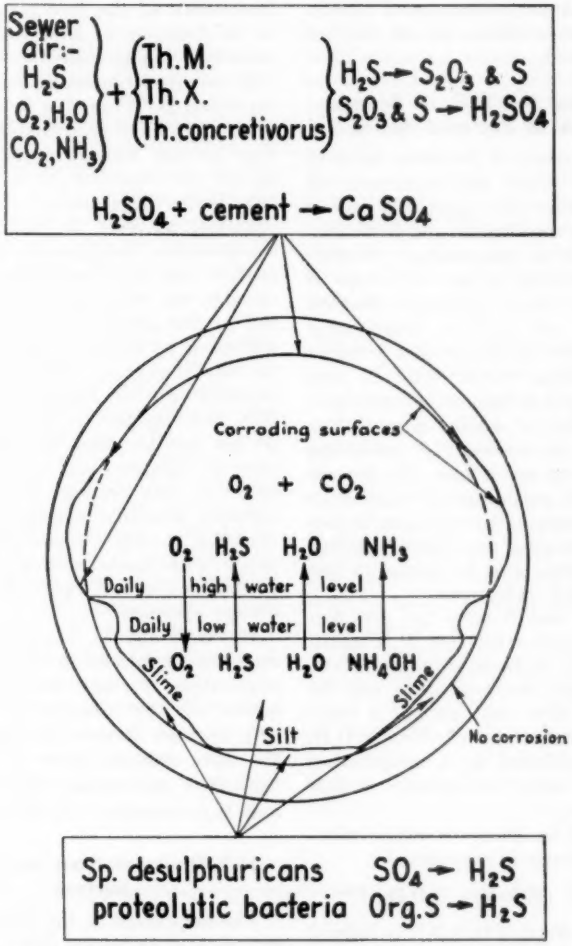

FIGURE 1.—Factors in bacterial corrosion of concrete sewers.

sewer when incubated in the presence of sewage in the laboratory generate H_2S at a rate of the same order as that observed in the sewer.

It would appear that slimes and possibly silt deposits do play a significant part in the generation of H_2S under most conditions and that their removal may be expected to substantially reduce H_2S conditions in any given sewer. Observations in Perth, Western Australia, by the Metropolitan Water Supply, Sewerage and Drainage Department during the first use of a new concrete rising main, indicate, however, that some H_2S generation can occur where slime or silt deposits are definitely absent.

No satisfactory detailed explanation of the microbiochemical changes which

occur during the generation of H_2S in flowing sewage, slimes, or silt has yet been advanced.

Conditions for H_2S in Sewage Because of Bacterial Action

It is obviously of practical value to be able to relate the occurrence of H_2S in sewage in a particular sewer with sewage constitution and sewer conditions such as temperature, ventilation, sewage velocity, size and shape of sewer, and other hydraulic factors. Knowledge of such a relationship would enable one to predict whether H_2S conditions would arise in new sewers under a defined set of conditions, and the effect of adding a particular trade waste on existing H_2S conditions in an existing sewer line. In the application of partial purification as a remedial measure, it would also be useful in determining the degree to which the purification must be carried to just eliminate H_2S conditions.

Pomeroy and Bowlus (9) put forward the proposition that H_2S conditions are only influenced by the B.O.D. of the sewage, its temperature, and the velocity of flow, and set out a table relating velocity to effective B.O.D. (B.O.D. multiplied by a temperature factor) for which no build-up in H_2S would occur.

As stated by Davy (4) these tabulated values can be expressed by

$$V = 0.137 \text{ (Effective B.O.D.)}^{0.496}$$

in which "effective B.O.D." is defined as (measured B.O.D.) (1.07^{t-20}), t being the sewage temperature in °C.

Davy (4) has shown that a better fit to observations made in Melbourne sewers is given by relating the Reynolds number to effective B.O.D. with an equation of the form:

$$N_{Re} = C\left[\frac{A}{b}\text{ (B.O.D.) } f(T)\right]^{1/n}$$

in which N_{Re} is the Reynolds number, C is a constant, A is the cross-sectional area of the sewage flow, b is the surface width of the flow perpendicular to the direction of flow, B.O.D. is the measured 5-day B.O.D. at 20°C., $f(T)$ is a function of the temperature expressed as °C., and n is a constant. Such simplified relationships have a very definite field of usefulness, but should be regarded as a first step only in the development of a general equation, as they do not take into consideration the generally agreed upon fact that H_2S conditions are influenced by the oxidation-reduction potential of the sewage, which is in turn influenced by the age of the sewage and the rate of oxygen solution. They also consider only conditions under which H_2S build-up just fails to occur and do not predict rates of H_2S increase once the balance point is passed. The observed data are also limited to essentially domestic sewage and it is doubtful if such a relationship would apply with trade wastes of various composition or with partially purified sewage effluents.

It would appear, therefore, that to establish a relationship with the widest application, further detailed investigation of the quantitative relationship between factors affecting each of the three separate parts of the problem—H_2S generation, H_2S emission, and H_2S oxidation—is required.

H_2S Emission from the Sewage Surface

The next stage in the process is the evolution of hydrogen sulfide gas from the sewage surface into the sewer atmosphere. It is not only sufficient that H_2S be present in the sewage, but also requires that it be able to escape into the sewer atmosphere. As described later, it is the conversion of the H_2S in the sewer atmosphere into sulfuric acid on the above-water walls of the sewer which is ultimately responsible for its corrosion. The amount of H_2S emitted from the sewage surface, therefore, is obviously one factor in determining the

rate at which the concrete will be attacked.

The factors influencing the rate of emission of H_2S include the following:

1. The concentration of sulfides, or, more explicitly, the concentration of undissociated hydrogen sulfide in the sewage film at the surface, which in turn is determined by the total sulfide content, the pH, and the presence or absence of heavy metal ions, such as iron, copper, or zinc.

2. The thickness of the thin "laminar" layers in sewage and air adjoining the sewage-air interface (see figure 2). The passage of sulfide molecules through these layers takes place at rates approaching those applying to molecular diffusion while, in the body of sewage and air, these rates of diffusion are the very much greater ones applying to "eddy" diffusion. The thickness of these layers is influenced by the velocity, size, and shape of sewage and air streams, respectively. The thickness of the air film is particularly influenced by the relative velocity of the air to the sewage.

3. The presence or absence of floating and/or adsorbed surface films on the sewage surface which may form an added resistance to passage of sulfides between phases.

Some investigations have been made in Melbourne with a view to ultimately establishing an empirical relationship between the rate of sulfide emission (per unit of sewage surface area per unit of time per unit partial pressure potential) and the various influencing factors. In passing, attention is drawn to the fact that the processes of oxygen absorption at the sewage surface and evaporation from the sewage are similar in many respects to that of sulfide emission.

H_2S Fixation and Oxidation on Concrete Sewer Walls

The further stage of the corrosion process is the fixation of the H_2S present in the sewer atmosphere on the above-water walls of the sewer and its conversion to sulfuric acid, followed by the attack of the acid so formed on the cement constituents of the concrete. The conversion of the gaseous H_2S to sulfuric acid is brought about by bacterial action (7) (8).

This part of the corrosion process may be explained as follows: The exposed walls of new concrete sewers with an initial pH of 11 to 12, on exposure to a sewer atmosphere containing hydrogen sulfide, are subject to a twofold chemical change. Normal carbon-

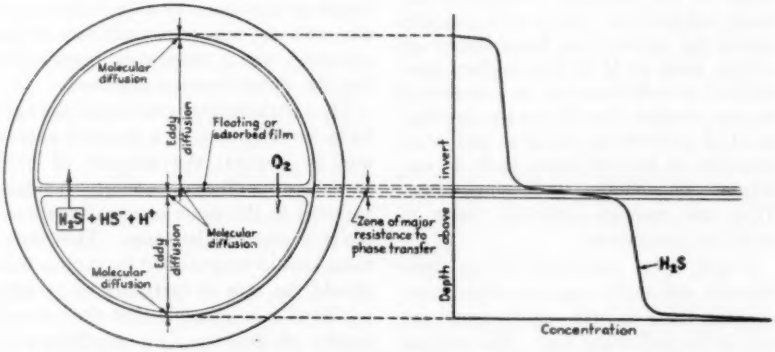

FIGURE 2.—Transfer of gases between phases, showing factors involved in sulfide emission and oxygen absorption.

ation lowers the pH to 8.4 (the pH of the carbonate-bicarbonate-carbon dioxide equilibrium) and fixation of hydrogen sulfide as thiosulfuric and polythionic acids further lowers the pH to about 7.5. While these purely chemical changes are taking place, there first occurs bacterial proliferation of a miscellaneous group of organisms capable of slow thiosulfate oxidation. The oxidation by this group of the sulfur acids formed chemically does little to assist the drop in pH and may actually retard it. As the pH drops below 9.0 the group of bacteria at present referred to as *Thiobacillus X* (previously described as *Th. thioparus-like*) multiply and their oxidation of thiosulfate and polythionate to sulfur and sulfuric acid results in a rapid drop in pH. This continues until the pH falls below 5.0, when *Thiobacillus concretivorus* produces high concentrations of sulfuric acid, and the pH frequently drops as low as 1.0. The early stage prior to the development of the *Th. X* group is the slowest and the corrosion increase in rate with the proliferation first of *Th. X* group and then the *Th. concretivorus* group.

The organisms *Th. X* and *Th. concretivorus* responsible for acid formation from H_2S are what is known as autrophic bacteria, that is they are capable of growth and biochemical activity in the complete absence of organic compounds. Their only requirements for growth are some source of sulfur, such as H_2S, free sulfur, thiosulfate, or polythionates as a source of energy; carbon dioxide for the development of protoplasm; oxygen; and small amounts of mineral salts, such as ammonia, phosphate, and magnesium. They also require sufficient water in which to proliferate.

Under sewer conditions where these bacteria are active and corrosion is occurring, these growth requirements are met in the following way. The oxygen is a normal constituent of the sewer air, H_2S is a necessary prerequisite for corrosion, and CO_2 is usually present in the sewer air in concentrations somewhat greater than the atmospheric air. Ammonia is also present, due to emission from the sewage, and is fixed on the acidic corrosion products. The phosphate and magnesium comes by solution from the cement in the concrete, but may also be derived to some extent from the sewage by diffusion. The water is derived from the moisture in the sewer air.

The rate of activity of the corrosion process being influenced by any of these various factors, it may also be limited by any one of them. Thus, other factors being optimum, the rate of acid formation may be determined by the concentration of H_2S in the sewer air. It may also be influenced by the concentration of CO_2 and of ammonia. It may also be determined by the moisture content of the corrosion products, which is in turn influenced by the relative humidity of the sewer air and the diffusion of water up from the sewage surface by capillarity. It may also be affected by the availability of phosphate and magnesium from the concrete being attacked or from the sewage.

Attack of Acid on Concrete

The final stage is the reaction between the sulfuric acid formed by bacterial oxidation of the H_2S in the sewer air, with the cement constituents of the concrete; this is ultimately responsible for the disintegration observed.

The nutrient requirements of the bacteria involved are of a general nature and in general the amount of acid formed on different concrete surfaces exposed to the same aggressive atmosphere should be the same. This statement should be qualified by saying that should the rate of corrosion be greatly inhibited it is possible that the rate of supply of lime may be insufficient to neutralize the acid formed and the bacterial action may be slowed down by

the intense acidity which would build up under such conditions.

Even with constant acid formation it is possible that concrete of different mix or cement of different chemical composition will be attacked at different rates under identical conditions in the sewer air. The lime of the cement is the primary reactant in the concrete. This neutralizes the acid formed from H_2S and it is reasonable that a definite amount of acid will react with a greater volume of concrete when the mix is lean than when it is rich in cement. The denseness of the concrete may also influence the readiness with which the acid can penetrate and react with the lime.

An extensive literature has been established on the attack of concrete by neutral sulfate salts. It is probable that this form of attack first occurs by reaction of the sulfate with the hydrated tricalcium aluminate to form calcium sulfoaluminate, which brings about a marked expansion in the concrete. It has been shown that aluminous cement (ciment fondu), pozzolan-portland cement mixes, and portland cement low in tricalcium aluminate are less rapidly attacked by sulfates. With H_2S attack the aggressive agent is principally, if not entirely, sulfuric acid and it is feasible that to some extent behavior towards neutral sulfates should run parallel with that towards H_2S.

There is very little quantitative information concerning the relative rates of attack on concrete made with these modified cements when exposed to H_2S, but it does appear definite that ciment fondu is attacked at a slower rate than normal portland cement concrete.

The exact way in which the various cement constituents react in the presence of H_2S attack is not yet known and further investigation into this aspect may well suggest methods of improving the resistance of the concrete by modifying the cement constitution.

Remedial Measures

The reason for referring to remedial measures in this paper is not to present a discussion of the relative merits of each, but to illustrate how the complicated series of steps in the corrosion process may be interrupted by the variety of mitigative measures available.

Discharge of Sulfides into Sewers

1. Elimination of trade wastes containing sulfides.—In some cases this will remove a local H_2S condition due purely to the discharge of such an industrial waste.

H_2S Generation in Sewers

2. Reduction of concentration of sulfates in sewage.—This may be possible in some cases where the sulfate concentration is due to the discharge of tidal or sea water to the sewer by industry. The prohibition of such discharges may reduce the sulfate concentration to a safe level, but in most cases this is unlikely, as the sulfate contributed in domestic sewage is usually sufficient to produce 2 to 3 p.p.m. of H_2S.

3. Partial purification of the sewage.—This can be carried out by sedimentation and high-rate treatment on filters. This reduces the organic content and so slows down the rate of H_2S production from sulfate. It also raises the oxidation-reduction potential of the sewage and so makes conditions less suitable for H_2S generation.

4. Dosage with chemicals to raise the oxidation-reduction potential of sewage.—Allen (1) has shown that the addition of nitrates or nitro compounds (such as nitrobenzene, dinitrobenzene, picric acid, and T.N.T.) in sufficient concentration will raise the oxidation-reduction potential of the sewage sufficiently to inhibit H_2S generation. The amounts required probably make this form of treatment impracticable.

5. Aeration. — Pomeroy has described the value of blowing air into the bottom end of rising (force) mains in reducing the H_2S generation. This also has the effect of retarding the drop in oxidation-reduction potential necessary for H_2S generation to occur.

6. Chlorination. — Treatment with chlorine removes by oxidation any H_2S present in the sewage and prevents further generation because of its bactericidal reaction on the bacteria involved. Although its exact function and effectiveness is open to doubt, it is probable that chloroben (an emulsion of mixed dichlorbenzenes) also has a bactericidal action on the bacterial processes.

7. Removal of slime and silts.—This has the effect of removing the site of much of the H_2S generation and may be expected to diminish the H_2S concentration in the sewage considerably. Silt may be removed by flushing, or its deposition prevented by increased velocities. A satisfactory method for the removal of slime in practice has not yet been described, but laboratory experiments suggest that chlorinated benzenes may be effective.

8. Reduction in detention in rising mains and increase in velocity in gravity sewers.—The rate of H_2S generation through rising mains can be reduced by increasing the rate of flow. Where abnormal increase in H_2S concentration occurs because of detention in sewers in which the sewage is backed up, H_2S conditions may be alleviated if this detention is eliminated. With gravity flow in sewers, the higher the velocity the less will be the H_2S build-up. Where this is possible, an increase in velocity of flow will diminish the H_2S build-up.

Emission of H_2S from Sewage

9. Reduction in turbulence.—Localized H_2S conditions sometimes arise through excessive turbulence of flow, such as at the junction of two sewers. By structural alterations it may be possible to substantially reduce the emission of H_2S into the sewer air and so reduce the rate of attack.

10. Dosage with heavy metal salts. —The addition of salts of copper, iron, or zinc to the sewage has the effect of throwing out the sulfides as insoluble sulfides of the heavy metals and so preventing emission into the sewer air. Ferrous or ferric salts do not completely precipitate the sulfide and, therefore, only partially reduce the transfer of H_2S from the sewage to the sewer air.

11. Dosage with alkalies.—Dosage with lime or soda ash to raise the pH of the sewage above 8.5 has the effect of increasing the degree of dissociation of the sulfide present. As it is only the undissociated sulfide which is available for transfer from sewage to sewer air, the increase in pH has the effect of reducing the effective concentration of available sulfide and so reducing the rate of emission into the sewer atmosphere.

12. Running sewer full.—As it is necessary for H_2S to be emitted into the sewer air for corrosion to occur, the elimination of the sewer air by running the sewer full will obviously eliminate the problem.

Rate of H_2S Fixation on Concrete

13. Ventilation. — Conditions optimum to bacterial fixation of H_2S may be disturbed by an alteration in the conditions of ventilation. Either by better natural ventilation or by forced ventilation by fans, one or more of the necessary factors for optimal bacterial activity may become limiting. It is probable that the factor most often concerned is humidity rather than H_2S concentration.

14. Periodic wetting of above-water walls of sewer.—The bacterial population essential to the corrosion process requires a particular chemical environment in which to proliferate and this takes time to develop. It would appear that if this environment were de-

stroyed as it is built up, by periodic flooding of the sewer, the development of active corrosion would be permanently retarded. Experimental work shows that regular wetting of an attacked surface by heading back the flow will inhibit corrosion. The frequency of wetting required depends on the present condition of the sewer and the intensity of the corrosive conditions in the sewer atmosphere.

15. Use of resistant concrete.—As previously stated, it is feasible that ciment fondu, super-sulfated metallurgical cement, pozzolan-portland cement mixtures, or portland cement low in tricalcium aluminate may be more resistant to attack than normal portland cement, but no definite quantitative evidence is available on this point as yet.

16. Ammoniation. — A patent by Pomeroy (10) claims that corrosion may be controlled by dosing the sewer atmosphere with ammonia, whereby it will be absorbed by the acid walls, the acid will be neutralized, and the corrosive action will cease. In view of the fact that active bacterial fixation of H_2S occurs up to a pH of 8.4 and neutral ammonium sulfate is the most aggressive of the sulfates towards concrete, it is unlikely that this treatment would have any great value.

17. Protective coatings. — In the United States synthetic resin-based plastic (Amercoat) has been tried as a lining for concrete sewers. The function of such inert linings is to isolate the concrete from the corrosive atmosphere. It is too early to know the behavior of such material under prolonged exposure to H_2S, but early reports are favorable. There would appear to be practical difficulties in the application of such a lining to an existing sewer undergoing attack.

Acknowledgments

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PROGRESS OF PURIFICATION DURING THE STARTING OF A TRICKLING FILTER*

By G. R. Grantham and J. C. Seeger, Jr.

One of the aspects of trickling filter operation about which little information is available is the progress of B.O.D. removal and nitrification during the period of starting operation, whether it be a new filter or one which has not received organic loading for some time. It is of practical interest to know how long a period is required to obtain a certain degree of treatment and of academic interest because the information gathered gives insight into the manner of treatment in a filter bed.

The consensus (1) (2) is that it takes several weeks to several months to "ripen" a trickling filter. Rudolfs, Heukelekian, and Chamberlin (3) reported the results of starting crushed stone, slag, gravel, and wire mesh experimental filters, about which they state: "From the chemical and bacteriological results obtained it was determined that the building-up or working-in period required about three months." It is believed that the terms "ripening," "building-up," and "working-in," as used above, refer to the period required for equilibrium conditions to manifest themselves. The information reported by Rudolfs *et al.* (3) is divided into two time periods—the first three months, and the last three months, with a two-month period dividing the two. Data and graphs presented by these workers were based on monthly averages and it is believed that much valuable information was lost to the literature in this method of analysis of collected data. A study of the B.O.D. and nitrification relationships in the oxidation reactions in organic wastes indicates that a considerable degree of purification should be obtained before equilibrium conditions are reached. If such were true, trickling filters could be used periodically and only when receiving stream conditions dictate their use. Considerable saving in pumping costs may be effected where topographical conditions are favorable for such operation.

*Final report of Project 4801A, Engineering and Industrial Experiment Station, University of Florida, Gainesville, Fla.

Experiments

Three series of experiments were performed at the Sanitary Research Laboratory, Department of Civil Engineering, University of Florida, to determine the progress of purification during the starting of standard-rate trickling filters. The filters used were 3 ft. square and 8 ft. deep (in Series 3, only 6-ft. depth was used), and so constructed that each 2-ft. depth of filter media was supported independently. A 3-in. open space existed below each 2-ft. interval for the purpose of sampling and inspection. Settled sewage was distributed by means of a single fixed nozzle for each filter bed. The loading used was in the standard-rate range and was intermittent with approximately equal (2.5-min.) dosing and resting periods. Filters No. 1, 2, and 3 contained slag salvaged from the old Campus treatment works and stored in the weather for about two years before the start of Series 1. Filter No. 4 contained new slag supplied through the courtesy of G. A. Mattison, Woodstock Slag Co., Birmingham, Ala. Rock sizes were as follows: Filter No. 1, ⅞ to 1½ in.; filter No. 2, 1½ to 2½ in.; filter No. 3, greater than 2½ in.; and filter No. 4, 1½ to 2½ in.

Series 1 was begun July 8, 1949, and was terminated 26 days later on August 3, 1949. To contrast summer and winter conditions, Series 2 was begun January 26, 1950, and was ended 44 days later on March 11, 1950. During this time, however, no particularly cold weather was experienced. A third series, run to determine the "residual" or "seed" effect of rock previously used as compared with rock which had not before been in contact with organic wastes, was begun January 5, 1951, and was ended 42 days later on February 16, 1951. These filters received no organic loading between series.

Daily "catch" samples, taken over about an hour's time, were removed at about the same time each day and analyzed for B.O.D., organic nitrogen, ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen, according to methods outlined in "Standard Methods" (4). Nitrogen analyses in Series 1 were run every other day on 2-day refrigerated composites. B.O.D. results for the first 5 days of Series 1 were not usable, due to the inadvertent use of dilution water containing greater than the tolerable amount of copper. During the first 5 days of Series 3, samples were taken twice daily. The 0-day sample in Series 3 was taken of the first sewage to be applied to the bed; because about 1 hr. was required to collect the sample, the results for that sample represent the effluent an average of 0.5 hr. after the beginning of the series. B.O.D. results for day 0 and day 0 + 6 hr. for filter No. 4 (new slag) are believed to be in error, due to a reducing agent being washed from the new slag, which caused the rapid uptake of iodine released upon addition

TABLE I.—Results of Series 1

Day	Reduction in B.O.D. (%)						Nitrification (%)						Av. Air Temp. (°F.)	Sewage Temp. (°F.)
	Filter No. 1		Filter No. 2		Filter No. 3		Filter No. 1		Filter No. 2		Filter No. 3			
	6-Ft. Level	8-Ft. Level	6-Ft. Level	8-Ft. Level	6-Ft. Level	8-Ft. Level	6-Ft. Level	8-Ft. Level	6-Ft. Level	8-Ft. Level	6-Ft. Level	8-Ft. Level		
2	—	—	—	—	—	—	—	—	—	—	—	—	83	86
3	—	—	—	—	—	—	6.9	7.6	18.1	19.3	1.6	4.6	84	88
4	—	—	—	—	—	—	—	—	—	—	—	—	84	86
5	91	95	95	95	87	85	29.3	40.3	47.2	—	8.8	5.9	86	86
6	96	95	95	98	89	92	—	—	—	—	—	—	84	88
7	95	95	95	93	80	90	71.9	68.7	65.0	70.0	23.4	26.4	84	89
8	96	96	92	96	86	89	—	—	—	—	—	—	85	88
9	89	92	71	86	77	77	75.5	81.4	61.7	69.9	55.3	62.4	86	88
10	81	85	75	67	70	57	—	—	—	—	—	—	80	86
11	79	82	86	83	69	81	63.3	70.0	59.1	37.3	39.6	53.5	81	86
12	85	87	85	89	74	88	—	—	—	—	—	—	78	86
13	81	83	85	91	78	88	58.6	71.0	72.4	—	50.8	64.6	80	84
14	87	86	86	90	75	83	—	—	—	—	—	—	83	84
15	87	86	87	87	79	81	74.7	42.5	57.3	80.7	66.6	70.7	83	86
16	90	87	90	90	80	87	—	—	—	—	—	—	83	84
17	92	90	85	89	79	87	90.0	86.5	87.4	82.2	70.3	82.0	82	86
18	94	95	92	92	84	88	—	—	—	—	—	—	83	86
19	80	82	75	82	78	86	70.0	56.2	64.8	82.9	62.3	76.8	83	86
20	—	—	—	—	—	—	—	—	—	—	—	—	84	86
21	87	91	88	91	75	82	—	—	—	—	—	—	86	86
22	86	90	78	89	74	88	88.6	91.0	75.4	86.1	57.2	82.9	88	86
23	87	88	78	89	74	83	—	—	—	—	—	—	88	86
24	83	84	74	80	82	74	83.6	82.5	75.5	80.0	77.4	80.7	83	86
25	85	93	82	88	80	74	—	—	—	—	—	—	80	84
26	90	92	87	92	84	85	85.3	87.6	79.5	88.0	75.3	80.2	79	84

of acid in the Winkler dissolved oxygen test. This difficulty had apparently ceased by sampling time on day 1. None of the samples in the entire experiment were settled.

The average hydraulic loading during Series 1, 2, and 3 was 3.1, 3.0, and 2.9 m.g.a.d., respectively.

The results of the experiment, expressed as per cent reduction in B.O.D. and per cent nitrification, are shown in Tables I, II, and III. Percentage nitrification is computed by dividing four-fifths of the NO_2-N plus the NO_3-N by the total nitrogen in the sample. Average air temperature and sewage temperature data are included in Tables I, II, and III.

Discussion of Results

This discussion is prefaced by the thought that throughout the entire ex-

TABLE II.—Results of Series 2

Day	Reduction in B.O.D. (%)						Nitrification (%)						Av. Air Temp. (° F.)	Sewage Temp. (° F.)
	Filter No. 1		Filter No. 2		Filter No. 3		Filter No. 1		Filter No. 2		Filter No. 3			
	6-Ft. Level	8-Ft. Level	6-Ft. Level	8-Ft. Level	6-Ft. Level	8-Ft. Level	6-Ft. Level	8-Ft. Level	6-Ft. Level	8-Ft. Level	6-Ft. Level	8-Ft. Level		
0	—	—	—	—	—	—	—	—	—	—	—	—	73	77
1	77	77	71	71	63	65	2.6	6.5	3.1	1.8	1.1	1.5	73	—
2	85	90	83	87	81	79	3.3	4.9	2.1	3.8	0.6	1.8	—	—
3	85	83	84	87	84	87	15.6	17.0	2.5	4.2	0.5	0.9	72	79
4	86	90	82	85	83	89	4.9	7.3	2.8	6.2	0.9	1.9	70	75
5	76	89	58	70	73	68	4.7	11.1	3.7	4.9	0.7	2.0	72	75
6	77	85	71	77	62	53	8.8	12.4	5.6	7.4	1.7	2.7	73	75
7	92	92	89	91	78	71	37.0	47.3	13.2	16.2	1.9	3.6	73	75
8	86	91	81	92	73	78	30.9	48.5	13.7	32.7	2.2	4.5	73	75
9	89	93	84	86	82	86	23.6	50.1	12.1	26.8	3.4	6.0	75	75
10	79	88	66	65	65	74	39.2	73.7	24.4	41.8	12.2	24.8	66	—
11	80	88	80	85	72	78	30.4	61.7	34.8	48.5	12.6	23.0	66	75
12	83	86	84	87	83	81	24.1	33.4	25.3	26.0	12.0	18.6	67	75
13	90	91	75	82	74	81	25.0	38.5	15.1	34.8	6.4	23.6	69	77
14	90	92	87	89	69	78	44.8	56.7	27.8	47.2	3.3	—	68	77
15	82	84	82	83	62	70	30.6	50.5	22.0	32.3	2.9	6.8	66	77
16	90	95	83	83	65	79	61.0	72.7	46.5	59.3	7.3	15.0	72	77
17	82	85	80	82	38	47	33.6	53.5	65.8	62.8	5.2	8.2	—	—
18	39	41	24	28	35	39	53.5	61.8	46.5	57.3	19.1	31.6	72	75
19	83	89	85	84	59	83	58.7	65.1	39.2	62.8	11.6	20.2	73	75
20	84	93	78	89	63	65	48.3	70.8	35.0	65.0	14.7	22.0	73	75
21	84	91	81	85	70	79	44.9	60.2	28.6	45.6	11.5	22.0	58	75
22	52	71	67	77	67	74	67.7	66.1	20.1	53.9	9.0	14.5	56	75
23	78	80	76	75	54	66	42.6	47.3	18.7	31.1	11.6	15.5	52	75
24	83	81	72	83	53	66	47.0	59.0	23.2	34.1	8.7	9.6	54	—
25	72	76	73	77	58	70	46.7	63.6	28.6	39.7	9.7	16.3	59	75
26	83	85	80	87	65	79	51.0	66.3	37.2	49.0	8.2	15.1	57	75
27	78	88	59	69	62	76	47.3	70.7	20.4	32.9	5.4	13.5	61	77
28	87	89	65	83	57	75	63.8	71.8	31.1	54.0	11.7	28.8	62	77
29	81	91	43	69	52	48	60.5	74.7	40.2	38.8	17.5	39.6	65	77
30	84	92	57	82	56	62	58.5	73.9	52.7	65.5	12.6	22.4	59	75
31	78	90	53	72	68	55	57.0	83.0	43.6	68.0	21.4	37.5	—	—
33	84	90	45	59	43	45	52.9	67.6	34.4	49.8	8.3	17.8	61	75
34	95	96	84	90	60	74	75.2	87.0	66.7	63.4	29.6	62.3	59	75
36	85	92	76	84	44	22	67.0	79.8	44.6	68.0	10.9	22.0	54	75
38	81	82	59	76	49	71	74.2	75.9	56.3	73.8	32.4	—	64	75
40	90	95	88	88	59	68	82.2	85.4	59.3	75.0	28.6	61.1	64	75
42	69	75	82	84	23	38	53.2	47.2	48.5	70.0	8.1	22.7	57	73
44	68	76	73	70	0	19	68.0	74.2	54.3	69.2	20.0	29.7	61	75

TABLE III.—Results of Series 3

Day	B.O.D. Reduction (%)		Nitrification (%)		Av. Air Temp. (° F.)	Sewage Temp. (° F.)
	Filter No. 2	Filter No. 4	Filter No. 2	Filter No. 4		
	6-Ft. Level	6-Ft. Level	6-Ft. Level	6-Ft. Level		
0	54	−10	19.3	0.8	63	74
0+6 hr.	70	26	—	—	—	—
1	82	54	8.2	0.6	66	73
1+6 hr.	82	56	—	—	—	—
2	87	71	10.4	0.5	53	74
2+6 hr.	89	64	—	—	—	—
3	79	66	4.9	0.4	36	75
3+6 hr.	61	63	—	—	—	—
4	59	26	2.1	0.4	42	72
4+6 hr.	69	75	—	—	—	—
5	67	71	1.8	0.8	52	70
5+6 hr.	52	60	—	—	—	—
6	80	80	2.3	0.6	53	69
7	71	82	3.6	0.4	57	71
8	72	59	25.1	0.3	62	71
9	68	59	13.6	0.7	67	75
10	70	80	—	0.5	54	74
11	77	84	8.9	0.4	44	76
12	75	79	44.3	0.5	51	71
13	88	87	22.7	0.6	58	71
14	72	81	42.7	0.7	62	73
15	87	81	31.7	0.8	63	72
16	88	79	44.0	0.3	60	69
17	84	80	33.4	0.3	54	69
18	82	76	64.7	1.0	59	69
19	86	81	68.3	0.8	58	73
20	88	83	46.0	0.5	44	73
21	79	79	36.5	0.9	40	71
22	35	69	34.0	0.9	49	70
23	72	83	47.5	1.1	62	66
25	46	70	—	—	63	73
26	91	78	49.7	3.9	67	73
27	74	81	47.6	7.4	53	73
28	30	68	22.9	4.5	34	71
29	68	64	16.8	2.1	36	69
31	70	70	47.9	5.6	52	71
33	65	61	52.0	6.9	57	67
35	94	88	77.2	9.1	53	65
38	63	81	9.5	6.2	58	66
40	73	81	—	10.3	64	72
42	80	79	17.1	16.4	61	72

periment the only filter medium used was blast furnace slag and that, although results of this test on similar media would probably be comparable, no blanket statement about early efficiencies for all filter media is intended.

From the information gathered in this test it appears that when a new or previously used slag-filled trickling filter is put into operation, the removal of B.O.D. from applied sewage begins quickly and is considerable in amount. The B.O.D. reduction at day 1 in Series 2 and 3 was between 54 and 82 per cent, and at 5 days in Series 1, 2, and 3 it was between 70 and 94 per cent at the 6 ft. level, the lower values in each case being the "new" rock values. The curves in Figure 1 indicate that initial removals are high and, because the re-

movals are high even in filter No. 4 with "new" rock, it would appear that considerable B.O.D. is removed by adsorption or other contact phenomena on the rock. There seems to be little or no lag in the onset of oxidation, as evidenced by the rapid increase in per cent removal. The value of the "seed" on used rock in the oxidation reaction is given by the vertical difference between the two curves in Figure 1. After day 7 the "new" and "used" beds afford approximately equal removals of B.O.D. In all cases the percentage B.O.D. reduction curves had leveled off by or before day 15, indicating that, as far as B.O.D. reduction is concerned, equilibrium was attained. Several of the curves tend to show decrease in removal and become rather erratic after day 15, due to "sloughing" or unloading of the filters. Settling of the effluent would remove this difficulty in a treatment works.

Active nitrification appears to begin between day 3 and day 9, depending upon temperature and rock size for "used" rock beds, whereas it takes considerably longer (25 days in this test) for new rock. This offers further evidence that there is considerable benefit derived from the "seed" in the "used" bed. Equilibrium, as far as nitrification is concerned, takes considerably longer than for B.O.D. reduction. In fact, nitrification equilibrium was not reached in any of the three series. The degree of nitrification appears to be considerably more closely related to temperature than is the degree of removal of B.O.D. Due to the size of filters used and to the open construction, air temperature rather than sewage temperature was the regulating value, for actual observation proved that at and below the 2-ft. level, the liquid temperature compared closely with the air temperature, and further, when the relative humidity was below about 80 per cent, it compared closely with the wet-bulb temperature. The wide difference between percentage nitrification in the summer (Series 1) and winter (Series 2 and 3) is probably due to a combination of lower temperature and lower relative humidity, but because incomplete data were kept of actual temperatures in the filter, no rigorous formulation of the nitrification-temperature relation-

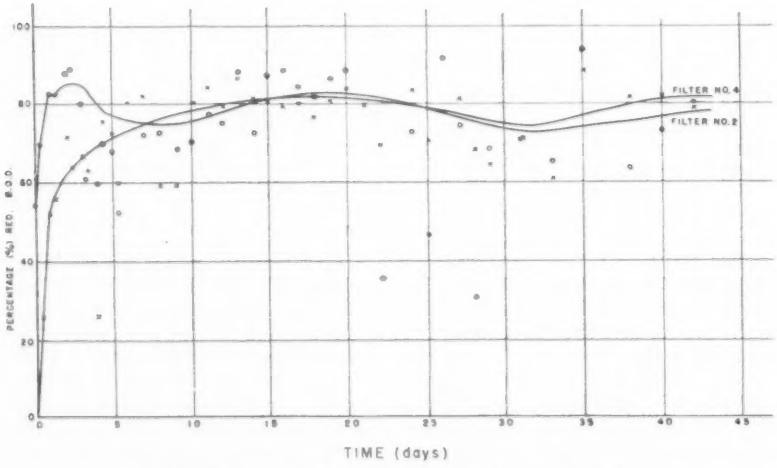

FIGURE 1.—B.O.D. reduction at 6-ft. level; Series 3.

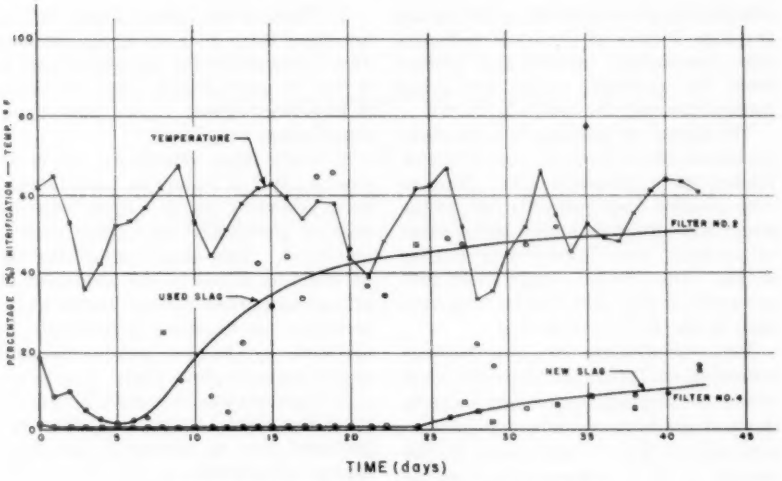

FIGURE 2.—Nitrification at 6-ft. level; Series 3.

ship is possible. Of interest, however, is the close correlation of air temperature and actual plotted points of percentage nitrification as shown in Figure 2. However, in the conventional trickling filter the size, construction, and method of distribution would probably make sewage temperature the controlling temperature.

Another indication that there is residual seed in "used" rock is shown in Figure 2. The decrease in per cent

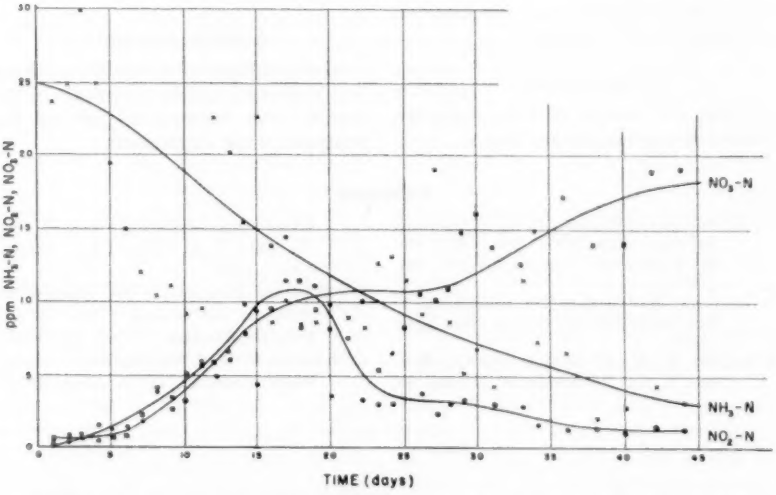

FIGURE 3.—Changes in nitrification components with time; Series 2, filter No. 2, 8-ft. level.

nitrification from about 20 to 1.8 during the first 5 days of Series 3 indicates that considerable nitrite and nitrate from the previous series are being washed through the bed.

The degree of treatment in the early periods is affected by the size of media. Higher early efficiencies were obtained with smaller rock, probably due to the larger adsorption areas and larger areas of residual "seed" afforded by smaller media. The effect is again more pronounced in the nitrification reaction than in the B.O.D. reduction.

The noticeable decrease in percentage reduction in B.O.D. at the time when active nitrification is starting is due to the now well-known difficulty in computation of B.O.D. reductions in the transition range where the second or nitrification stage commences (5).

The changes in the forms of nitrogen in the filter effluent with time after the starting of a trickling filter are shown in Figure 3. The results of filter No. 2 in Series 2 were chosen as typical in this respect. These curves indicate, indirectly, that the progress of oxidation in a trickling filter is not materially different from the progress of oxidation in a stream.

Conclusions

From the results of these tests the following conclusions are drawn:

1. There is a residual "seed" left on trickling filter rock upon discontinuation of operation for periods as long as a year or more, which, when operation is renewed, causes rapid recovery to equilibrium conditions.

2. High filter efficiencies, as measured by B.O.D. reduction, are obtained in a period of up to 7 days, whether new or previously used filter rock is employed. This should allow the use of trickling filters in the treatment of sewage and other organic wastes where treatment is required periodically as dictated by stream conditions and and changes in plant loads.

3. High efficiencies in B.O.D. removal upon first starting a trickling filter are probably due to adsorption or other contact phenomena by the filter rock. Also, little or no lag is observed in the onset of the oxidation reaction of the adsorbed material.

4. The nitrification reaction in the starting of a trickling filter is more dependent upon "seed," temperature, and rock size than is the B.O.D. reduction, but it follows the normal nitrification pattern as observed in stream recovery and elsewhere in nature.

Acknowledgments

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Industrial Wastes

DETERMINATION OF FAIR SEWAGE SERVICE CHARGES FOR INDUSTRIAL WASTES *

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The increasing consciousness of the seriousness and the magnitude of the industrial waste problem in this country has awakened interest in the corollary consideration of raising the revenue requirements for remedial works.

The magnitude of the problem is pointed up by a survey of the Public Health Service (1), which finds that there are 10,401 industries discharging wastes into the watercourses of the United States. Another survey by the National Association of Manufacturers (2) of more than 3,000 industries indicates that 82 per cent of the industries provide no treatment whatsoever. One interesting finding of this survey is that more than two-thirds (69 per cent) of the industries discharge all or a part of their wastes into the municipal sewage works. It is with this fraction that this paper is concerned.

With 11,811 municipalities having sewer systems, and 6,628 having sewage treatment plants (1), and recognizing that most receive industrial wastes to some extent, the magnitude of the present problem is apparent. And with 4,209 municipalities requiring new sewage treatment plants (1), the problem of the future will be magnified. This is particularly true because annual costs, usually quite low proportionately when sewage is discharged untreated through sewer systems, increase markedly when treatment facilities are provided.

This paper is concerned, therefore, with the problem of presenting a fair basis of charges to industry in the usual situation where its wastes are discharged into the municipal system. It is limited to a consideration of those wastes which are amenable to treatment in conventional plants, and excludes such wastes which because of their toxicity or chemical composition would cause serious difficulties in the plant or subsequently in the receiving waters.

The approach to this problem as presented herein lies in the principles enunciated by a Joint Group of 24 members consisting basically of committees of the American Society of Civil Engineers and of the Section of Municipal Law of the American Bar Association, but with representation by six other participating organizations, including this Federation. Samuel A. Greeley and John D. McCall served as general chairmen of the engineering and law committees, respectively. Other members of the Federation who served on the Joint Committee were Francis S. Friel, Thomas M. Niles, Myron W. Tatlock, and the writer. After more than three years of work the Committee has issued its report entitled "Fundamental Considerations in Rates and Rate Structures for Water and Sewage Works" (3).

* Presented at 24th Annual Meeting, Federation of Sewage and Industrial Waste Associations; St. Paul, Minn.; October 8–11, 1951.

Inasmuch as the report has not as yet been widely circulated, this paper of necessity must review the basic principles upon which it is founded to introduce the reader to the procedures involved as applied to the determination of fair charges for the handling of industrial wastes. However, for a complete discussion of the problem, the author recommends the report as representing the considered thought and judgment of a representative group of engineers, lawyers, and finance authorities interested in the question.

Certain Basic Considerations

Preliminary to a consideration of the methods of charging for industrial wastes handling in a municipal system, it is important to give consideration to certain basic factors involved. A municipality, in determining a course of action with respect to the reception of industrial wastes into its system, may consider, among others, the following possibilities:

1. To exclude industrial wastes:
   - (a) All industrial wastes.
   - (b) Certain industrial wastes which, because of their constituents (toxicity, acidity, etc.), impair the functioning of the municipal system.
2. To require pretreatment at the source:
   - (a) All industrial wastes to a level approaching the constituents in normal domestic sewage.
   - (b) Certain wastes which, because of their constituents or excessive load variation, are harmful to the system.
3. To receive industrial wastes:
   - (a) All industrial wastes.
   - (b) All wastes except those which are not amenable to treatment or would cause real difficulties in the operation of the system.

The decisions made concerning this question influence the financing problems confronting the city. Obviously, if course 1(a) is followed, no direct financial decisions need be made concerning the charges. But, because of the importance of industry in a community, this procedure is unrealistic. The costs of separate treatment by each industry are likely to be much greater than combined treatment, not to mention the administrative problems confronting regulatory agencies. Course 2(a) apparently simplifies the problem, because after pretreatment by industry to the level of ordinary sewage the industry can be charged at the rate for other general users of the system. It is subject, perhaps to a lesser extent, to the same objections as course 1(a)—namely, higher total costs and administrative difficulties. Course 3(a) is likely to result in certain wastes seriously destroying the efficiency of the sewage works or markedly increasing costs beyond a point of reasonableness. The admittance of very toxic wastes would be an example.

Thus, it will be apparent to most that the proper procedure, and that followed by most municipalities, is the middle ground represented by courses 1(b), 2(b), or 3(b), alone or in combination. According to the Public Health Service (1), more than 60 per cent of the industries contribute organic wastes. Most of these are susceptible to treatment in conventional processes. However, increased costs of construction and operation are involved, and this brings up the topic of charges.

Methods of Charging in Use

In the approximately 12,000 communities in this country having sewerage facilities, a number of methods are employed for raising the revenue required to construct and operate them; and, therefore, for charging industry

for the reception of its wastes. Some of these methods are:

1. The ad valorem tax on property. Historically (since colonial days) this has been the commonly accepted method (in more than 80 per cent of U. S. communities) of raising the revenue requirements. When the sewage works were limited to sewer systems with disposal into the nearest watercourse, operation budgets were small and, in general, this method brought few objections.

2. Special assessments. Special assessments on a front footage basis against abutting property are quite commonly used as a method of payment for all or a part of the cost of construction of sewer systems.

3. Sewage service charges. From the time of first application in Brockton, Mass., in 1894, sewage service charges have come to be used as a method of raising revenue. Although no complete recent surveys are available, it is estimated that approximately 1,000 municipalities (or one-sixth of those having treatment plants) now use this method of charging. A number of procedures are employed (as many as 12), the principal one being related to the volume of water consumed on the premises. In a few cases constituents in the sewage are included in the rates, in one way or another.

4. Special negotiated contracts with industry. The bases for these contracts vary, but in several the incremental (added cost) method has been employed.

5. Combinations of two or more of the above methods.

It is desirable to discuss certain of these methods in some detail. It is obvious that when the property tax basis is used to raise the total annual revenue (fixed charges and operation and maintenance costs), the use of, and the benefits received from the works is not measured. Used alone, this measure of ability to pay, rather than of service rendered, is no more valid than the old English system of taxing on the basis of number of windows on the premises. Fairness to all users and properties is not achieved by this method as the sole basis of charge. However, because the value of property, both developed and undeveloped, is enhanced by reason of the existence of the sewage works, this is some measure of benefit, the extent of which is discussed in a later section.

Attention is called to the use of the term "sewage service charge" rather than "sewer rental charge" or "sewer service charge." The Joint Committee believes that this terminology is more descriptive of what is included in the charge and leads to fewer necessary explanations. With this out of the way, it can be stated with equal validity that to base all charges on a schedule of sewage quantity or some similar base is improper. Under this method present users of the system pay an unfair proportion of the cost of the system, which is designed partly as a benefit to property. This also is discussed at length later. This method becomes even more unfair when excess collections are paid into the general fund, or are used to finance new construction or extensions of the sewer system.

Several writers have called attention to the incremental method of negotiating contracts with industry. This method involves determining the charge to industry on the added or excess cost basis, wherein the costs of a combined system are estimated, and by subtracting the costs of a system without industry being included, the incremental costs are determined. This method can be used in reverse. In some situations the industrial wastes make up half or more of the load. If the cost of a combined system is estimated and the cost of a plant for the industrial wastes is subtracted, a quite different answer results. Which is proper? This method is indefinite and not susceptible of ac-

curate analysis, particularly on a long-established system. And it changes with time, as industry and community growth is often different.

Where a combination of methods 1, 2, and 3 has been used, the allocation of costs sometimes approaches fairness. In the past, this has been happenstance only. Thus, where general obligation bonds have been issued, and a property tax employed for debt service, with sewage service charges for operation and maintenance costs, both property and users share in the costs, although not very often in a fair proportion.

Some of the methods of determining charges have been discussed in a general way. It was first planned to present in detail the methods of charging employed by a number of communities. Because of space limitations and in view of the wide variance in practice, it was finally decided that this would serve no useful purpose. Influenced by political expediency and precedent, and affected by the social philosophy of governing bodies in their outlook towards present and potential industry, charges vary from extremely low ones (a subsidy to industry, and unfairness to other classes of users and property) to burdensome and confiscatorially high ones. In general, past practice is of little aid in approaching the subject of fairness in charges.

Suggestions for Charges to Industry

Many articles have been published on the subject of charges for industrial wastes in a municipal system. These take many points of view. The literature is replete with suggestions that not only volume, but also strength, should be considered in making charges. Chronologically, and to mention only a few, Greeley (4), Marston (5), Calvert (6), Mohlman (7)(8)(9), Hommon (10), Mahlie (11), Knowlton (12), Besselievre (13), La Due (14), Russell (15), and Laboon (29) have suggested the desirability of considering sewage composition in determining charges. The methods proposed for accomplishing this have varied widely.

A number of writers have discussed and some have advocated the incremental method of charging for industrial wastes. Among these may be mentioned Warrick (16), Green (17), Enslow (18), Cohn (19), Gray (20), and Haseltine (21). Several have employed or advocated the use of formulas to determine service charges, including Symons (22)(23)(24)(25)(26), Wright (27), Reaves (28), and Laboon (29).

In general, these articles do not discuss the question of just what proportion of the total annual charges should be or are covered by the methods suggested or employed. Furthermore, in later years very little reference is made to the share which should properly be borne by property. Nor to the writer's knowledge is mention made of a reasonable allocation of the total annual costs except in papers by Greeley (30)(31)(32).

In foreign countries attention is also being given to this problem. Mohlman (8) discusses practice in the Emscher and Ruhr Districts, in Germany, where surcharges for industrial wastes based on production and type are made. The 1937 Public Health Act (Drainage of Trade Premises) (8)(33) in England states that in setting rates, " . . . regard (shall be) had to the volume and composition of trade effluents and to any additional expense incurred in connection with their reception." And even England has its formula developers in the person of Townend (33). The Council of the South African Branch, Institute of Sewage Purification, adopted the following statement of policy (34):

"The charges for industrial waste disposal should be in relation to the waste load contributed by the industry.

"The charge levied against an industry

for the load contributed should not be made with a view to profit or loss, but should be based on the established cost price of treatment of the mixed sewage entering the works."

A rather unusual viewpoint (to many), but not surprising, perhaps, in view of the nationalization program in England, is the suggestion by Hurley (35) of a national basis of solution to this problem, with every manufacturer contributing to a central fund a standard amount based on character and volume. From the central fund local authorities would be reimbursed for treating the industrial wastes in their plants. It is hoped that neither our aims nor our tendencies are in that direction.

Returning to practice in the United States, the implications of the following statement in the Report of the Ohio River Committee (34) published in 1944 are intriguing:

"There are several basic considerations which underlie the problem of equitably distributing the cost of pollution abatement works. Among these considerations it may be contended that industries exist only in response to public demand for their products and, therefore, that the public is indirectly responsible for all stream pollution, both industrial and domestic, and ultimately must bear the cost of all pollution-abatement activities, either by direct expenditures or partially by direct expenditures and partially in the form of increased costs for industrial products."

In view of what has already been discussed concerning the confusion in practice and in the thinking on this subject, is it any wonder, therefore, that municipal officials and industries experience difficulty in approaching this problem? Fundamental considerations have been, and are being, more and more lost sight of.

Fundamental Principles Involved

The aim of engineers and administrators involved is to establish fair rates and rate structures which measure the benefits from, and use of, the sewage works. The approach to the problem can be found in a statement of fundamental principles involved, prepared after considerable thought and discussion by the Joint Committee:

"The needed total annual revenue of a water or sewage works shall be contributed by users and non-users (or by users and properties) for whose use, need, and benefit the facilities of the works are provided, approximately in proportion to the cost of providing the use and the benefits of the works."

From what has already been written, it is obviously unfair to raise the annual revenue requirements entirely by a charge on property, as is done when ad valorem taxes are employed to raise the total annual amount. Similarly, it is unfair to expect the present users to pay the entire cost, as is done when sewage service charges are designed to raise the entire annual revenue requirements.

The report goes on to state:

"It is considered that rates and rate structures for water and sewage works should achieve fairness through payment by each user or beneficiary of his fair share of the total annual cost of the works required, and no more."

The above general statement is one with which almost everyone will agree, but depending on where one "sits at the ball game" his viewpoint of what approaches fairness will differ. As applied to the subject of this paper, even the viewpoints of industrial representatives, who for purposes of our analogy should be on the same "team," will differ, depending on whether they represent a "dry" or a "wet" industry. The governing bodies and the citizens they represent may well be confused in their thinking.

In approaching the problem presented by the Joint Committee state-

ment of fundamental principles, it becomes necessary to consider its various component parts.

Total Annual Revenue Requirements

The annual revenue requirements of a sewage works may be divided for this purpose into those which are needed for (1) the collection system, including pumping stations; (2) the intercepting sewers; and (3) the treatment plant. The revenue requirements for these major units are commonly subdivided as follows:

1. Operation.
2. Maintenance and replacement. (The latter item may be covered by a depreciation expense item in some cases.)
3. Fixed charges or debt service, including interest and amortization of the bonds required to finance the construction of the project. A depreciation allowance may be provided where the useful life of the works, including obsolescence, does not correspond to the bond period.

All of the above three items of the various component parts of the works constitute important and essential items of expense in constructing and operating the system and should be included in any approach to a fair allocation of costs.

Contributions by Users and Properties

The Joint Committee report makes a definite point, and is predicated upon contributions by both users and properties. In justification of the premise, it will be readily apparent that surface and subsurface drainage is related to area or property and has no relation to use as represented by the discharge of "spent" water or sewage; therefore, a charge based upon area or property is proper for this element of service. Similarly, the provision of capacity in the component parts of a sewage works for the future provides for the security and development of property and for community growth, and is a proper charge on property, as it is obviously unfair to charge present users based on sewage contribution for this cost element. In fact, undeveloped property in fairness should provide the major portion of this cost, because capacity is provided for this later use. The amount allocated to property would decrease with time as the use of the works approached capacity. The charge to property can be distributed on a front foot, area, or property valuation basis, or on a combination method.

The user, on the other hand, is responsible for certain items of cost. A portion of the collection and intercepting sewer is allocated for his use. To a greater degree the fixed charges on the plant, and to an even greater extent the operating cost of the plant, is caused by his use of the works.

Allocation of Costs in Proportion to Benefits and Use

At the time of construction, or periodically thereafter, it is possible for an engineer to determine with reasonable accuracy the relative proportions of the works and of the costs which are chargeable to users and to property. Thus, a building sewer renders a direct service to the property benefited and is chargeable to that property. In proceeding downsewer (figuratively), a continually lesser proportion of the capacity of the sewer is chargeable against that property. In the case of the intercepting sewer it is possible to determine and allocate the portion of the cost chargeable to property (surface runoff, ground-water infiltration, future capacity, public use, etc.) and that chargeable to the user (domestic sewage, industrial wastes). Furthermore, in the case of the sewage treatment works the various parts are affected differently by the volume and characteristics of the liquid wastes and, therefore, the special service which par-

ticular users and properties (such as an industry, for example) receive, can and should be evaluated. Thus, the sewage pumping and sedimentation costs are affected in design and, therefore, in resultant costs, principally by volume. Oxidizing processes, on the other hand, are influenced principally by organic loading, and sludge disposal processes by solids content.

By attacking each unit of the sewage works in this manner it is possible, first, to allocate the various portions to use and to property, and then later to distribute these allocated amounts, depending on the actual expenditures which these cause. Having determined the amount to be allocated to property, it is possible to set up a schedule of charges to property based on front footage, area, or (more usually) assessed valuation. A combination has been used in at least one case. The allocation to users can be distributed on a volume, organic loading (represented by B.O.D.), and solids content basis. Depending on the situation, chlorine demand may replace or be used in conjunction with the organic loading.

Because the aim is to achieve fairness to all users and beneficiaries (domestic, commercial, and industrial alike), it becomes necessary to consider the question as a whole and not simply from the standpoint of any one class (such as an industry). Therefore, what might appear at first glance to be too broad an approach to the subject of this paper, should be justified to the reader as the detailed procedures involved are considered later.

Realizing the difficulty of considering this subject in abstract or general terms, the author has prepared a typical example of a situation, which will illustrate the procedures involved. Before considering this, it should be emphasized again that the basic consideration involved is that both users and properties should share fairly in raising the needed revenue requirements. Having determined this fair allocation, the distribution between various users and properties in a rate structure becomes a detail, although admittedly an important one.

Illustrative Example of Procedures Involved

Assumed Conditions

Assume that a rate schedule is to be determined for a community, with a present population of 30,000, in which a system of intercepting sewers and a sewage treatment plant have recently been constructed. In this community it is assumed that a large wet industry, among others, is located; and it is desired to determine the fair costs which should be charged that major industry. It is further assumed the wastes have a variation with time similar to domestic sewage, and are amenable to treatment.

1. Present flows and those used as a basis of design of the plant and intercepting sewers are as follows:

Flow Source	Present Average Flow (m.g.d.)	Flow Basis of Design (m.g.d.)	
		Plant (1970)	Sewers (2000)
Sewage[1]	3.00	4.50	12.00
Major industrial waste	0.75	0.90	2.00
Ground-water infiltration	0.50	0.60	2.00
Storm-water runoff	—	—	4.00
Contribution from public use	0.25	0.30	0.80
Total	4.50	6.30	20.80

[1] Sources exclusive of major industry.

2. The average strengths of the sewage and industrial wastes are assumed as follows:

	Susp. Sol. (p.p.m.)	5-Day B.O.D. (p.p.m.)
All sources excl. of industry	250	200
Major industrial waste	350	700

3. Assessed valuations are as follows:

Entire community (incl. major industry)	$20,000,000
Major industry	$500,000

4. Construction costs of the various units are as follows:

Unit	Constr. Cost ($)
Intercepting sewers[1]	700,000
Treatment plant:	
Main pumping station	
Equipment	30,000
Structures	25,000
Screen and grit chambers	30,000
Preliminary sed. tanks	90,000
Trickling filters	600,000
Final sed. tanks	180,000
Recirculation pumps	15,000
Chlorination[2]	40,000
Dig. tanks and vac. filters	160,000
Main control building	150,000
Plant water supply	50,000
Roads and grounds	50,000
Plumbing and heating	80,000
Total treatment plant	1,500,000
Total Construction Cost	2,200,000

[1] For purposes of simplicity, costs of collecting sewers are not included.
[2] Contact tanks and equipment.

5. It is further assumed that the fixed charges are limited to interest and bond retirement, and that the bond period corresponds to the useful life of the structures. Assumed debt service charges are bond retirement 4 per cent annually, and interest charges at an average of 1 per cent (2 per cent interest rate), or a total of 5 per cent.

6. Operation and maintenance costs are as follows:

	Labor and Supervision	Power and Light	Materials and Supplies	Maint., Repairs, and Replacements	Total
Intercepting sewers	$ 1,000	—	—	$ 1,200	$ 2,200
Main pumping station	3,000	$ 5,000	$ 200	1,000	9,200
Preliminary treatment	5,000	1,000	200	500	6,700
Secondary treatment	5,000	3,000	500	5,000	13,500
Effluent chlorination	2,000	—	3,000	200	5,200
Sludge disposal	7,000	2,000	4,500	4,000	17,500
General	1,000	2,000	1,000	1,000	5,000
Supervisory	6,000	—	200	—	6,200
Collection and billing	5,000	—	—	—	5,000
Total	$35,000	$13,000	$9,600	$12,900	$70,500

Allocation of Charges Between Users and Properties

Having set forth the assumed conditions, it becomes necessary to apportion the needed annual revenue requirements between users and property on the basis of the fundamental considerations that have been discussed. The total annual revenue requirements are, therefore, as follows:

Fixed charges:	
Intercepting sewers	$ 35,000
Treatment plant	75,000
Operation and maintenance costs	70,500
Total annual charges	$180,500

1. Fixed charges—intercepting sewers. Considering the allocation (between users and property) in the case of the intercepting sewers, it will be seen that the proportion of the capacity of the intercepting sewers used or occupied by storm-water runoff and ground-water infiltration bears no relation to the use made by the direct contributor of sewage or wastes and, therefore, is properly chargeable to property. In the same way, the proportion of the capacity provided for the future (50 years from present) is also a proper charge to property. It can similarly be shown that the contribution of sewage from the public use of water can reasonably be charged to property. In Figure 1 are shown the relative proportions which might be allocated to users and to property in

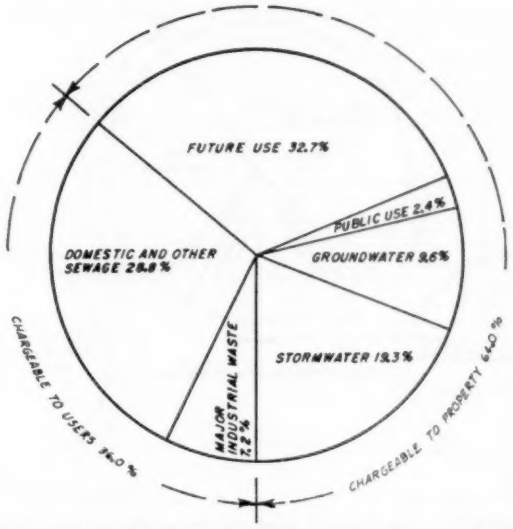

FIGURE 1.—Allocation of fixed charges on the intercepting sewers.

the case of fixed charges on the intercepting sewers. Of the total fixed charges on the intercepting sewers ($35,000), 19.3 per cent is caused by storm water (4.0 m.g.d. of the total capacity of 20.8 m.g.d.), 9.6 per cent by ground water, 32.7 per cent by future provisions, and 2.4 per cent by public use (municipal buildings, etc.), or a total of 64 per cent chargeable to property. The allocation to users is 28.8 per cent by domestic users and others, and 7.2 per cent to the major industry, or a total of 36 per cent.

2. Fixed charges—treatment plant. In the case of the fixed charges on the treatment plant (amounting to $75,000 annually), it will be seen that the relative proportion which should properly be charged to users and property will differ in the various units. Thus, the proportion chargeable to property in the case of screens and grit chambers, pumps, sedimentation tanks, conduits, and outfalls, in which the design is based principally on volume, will be considerably greater than for digestion tanks, in which the principal design consideration is the suspended solids removed from the sewage. Similarly, the principal design consideration in the case of secondary treatment is the B.O.D. of the sewage. Figure 2 illustrates the basic volume distribution between users and property for this part of the problem, and indicates that 59.5 per cent can properly be charged to present users and 40.5 per cent to property for works that are principally influenced by volume. It should be pointed out that 28.5 per cent of the total cost is chargeable to future use on a volume basis. As time progresses and subsequent allocations are made, this proportion should be reduced until it reaches zero in 1970 (the year for which the plant is designed).

In the case of plant units affected by organic and solids load, the proportion of the fixed charges chargeable to the future and, therefore, to property, can be estimated as follows:

	B.O.D. (lb.)	Susp. Sol. (lb.)
Present load (1950)	10,600	10,000
Design load (1970)	14,200	13,900
Chargeable to property (%)	25.4	28.1

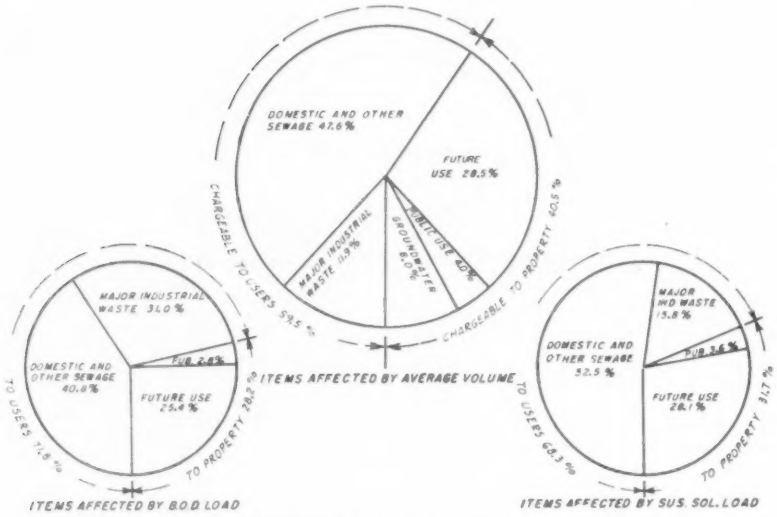
DOMESTIC AND OTHER SEWAGE 47.6%
FUTURE USE 28.5%
MAJOR INDUSTRIAL WASTE 13.9%
GROUNDWATER 6.0%
PUB. USE 4.0%
CHARGEABLE TO USERS 59.5 %
CHARGEABLE TO PROPERTY 40.5 %
ITEMS AFFECTED BY AVERAGE VOLUME
MAJOR INDUSTRIAL WASTE 31.0 %
PUB. 2.6%
DOMESTIC AND OTHER SEWAGE 40.8%
FUTURE USE 25.4 %
TO USERS 71.8 %
TO PROPERTY 28.2 %
ITEMS AFFECTED BY B.O.D. LOAD
MAJOR IND WASTE 15.8 %
DOMESTIC AND OTHER SEWAGE 52.5 %
PUB. 3.6 %
FUTURE USE 28.1%
TO USERS 68.3 %
TO PROPERTY 31.7 %
ITEMS AFFECTED BY SUS. SOL. LOAD

FIGURE 2.—Allocation of fixed charges on the treatment plant.

Allowance should be made for the load contribution from public use as well, and this portion charged to property. The ground-water infiltration is assumed to carry no load and, therefore, is ineffective on these plant units.

Certain plant units having general use, such as the main control building, plant water supply, roads and grounds, plumbing and heating, etc., are impossible to apportion accurately unless the details of a special situation are in hand. In this illustrative case these units are apportioned by the average percentages arrived at for all other units exclusive of these four items.

TABLE I.—Allocation of Fixed Charges

	Total Fixed Charges ($)	Chargeable to Property		Chargeable to Users ($)	User's Share Chargeable to					
					Volume		Susp. Solids		B.O.D.	
		(%)	($)		(%)	($)	(%)	($)	(%)	($)
Intercepting sewers	35,000	64.0	22,300	12,700	100.0	12,700	—	—	—	—
Treatment plant:										
Main pumping station										
Equipment	1,500	40.5	600	900	100.0	900	—	—	—	—
Structures	1,250	64.0	800	450	100.0	450	—	—	—	—
Screen and grit chambers	1,500	64.0	950	550	60.0	330	40.0	220	—	—
Preliminary sed. tanks	4,500	40.5	1,800	2,700	85.0	2,300	15.0	400	—	—
Trickling filters	30,000	25.0	7,500	22,500	10.0	2,250	—	—	90.0	20,250
Final sed. tanks	9,000	30.0	2,700	6,300	50.0	3,150	—	—	50.0	3,150
Recirculation pumps	750	25.0	200	550	—	—	—	—	100.0	550
Chlor. tanks and equip.	2,000	35.0	700	1,300	40.0	520	—	—	60.0	780
Dig. tanks and vac. filters	8,000	30.0	2,400	5,600	—	—	100.0	5,600	—	—
Sub-total	58,500	30.3	17,650	40,850	24.2	9,900	15.2	6,220	60.6	24,730
Main control bldg.	7,500	30.3	2,300	5,200	24.2	1,310	15.2	790	60.6	3,100
Plant water supply	2,500	30.3	800	1,700	24.2	410	15.2	260	60.6	1,030
Roads and grounds	2,500	30.3	800	1,700	24.2	410	15.2	260	60.6	1,030
Plumbing and heating	4,000	30.3	1,200	2,800	24.2	680	15.2	430	60.6	1,690
Total plant	75,000	30.3	22,750	52,250	24.3	12,710	15.2	7,960	60.5	31,580
Total fixed charges	110,000	41.0	45,050	64,950	39.2	25,410	12.2	7,960	48.6	31,580

TABLE II.—Allocation of Operation and Maintenance Costs

Structure or Function	Total Oper. and Maint. Cost ($)	Chargeable to Property		Chargeable to Users ($)	User's Share Chargeable to					
					Volume		Susp. Solids		B.O.D.	
		(%)	($)		(%)	($)	(%)	($)	(%)	($)
Intercepting sewers	2,200	60	1,300	900	60	500	40	400	—	—
Main pumping station	9,200	17	1,600	7,600	100	7,600	—	—	—	—
Preliminary treatment	6,700	50	3,400	3,300	50	1,700	50	1,600	—	—
Secondary treatment	13,500	15	2,000	11,500	10	1,200	—	—	90	10,300
Effluent chlorination	5,200	15	800	4,400	10	400	—	—	90	4,000
Sludge disposal	17,500	5	900	16,600	—	—	100	16,600	—	—
General	5,000	15	800	4,200	25	1,000	43	1,800	32	1,400
Supervisory	6,200	15	900	5,300	25	1,300	43	2,300	32	1,700
Collection and billing	5,000	15	800	4,200	25	1,000	43	1,800	32	1,400
Total	70,500	17.8	12,500	58,000	25.4	14,700	42.1	24,500	32.5	18,800

In total, the proportion of the total fixed charges on the plant ($75,000) allocated to property is $22,750, or 30.3 per cent of the total. For the entire system the distribution of the $110,000 fixed charges is $45,050 to property (or 41 per cent) and the balance (59 per cent) to users. The details of the allocation of the fixed charges are shown in the left-hand side of Table I.

3. Operation and maintenance costs. The allocation of the operation and maintenance costs, although approached in the same manner, results in quite different proportions charged to use and to property. Because dealings here are with present costs, charges for future capacity disappear and the proportion chargeable to the present users increases. Thus, in the case of power for sewage pumping, as an illustration, the proportion chargeable to property is 0.50 m.g.d. (infiltration) plus 0.25 m.g.d. (public use) divided by 4.50 m.g.d., or 16.7 per cent. In the case of sludge disposal facilities, however, because infiltration carries with it negligible suspended solids as they affect this operation, a maximum of 0.25/4.50 (or 5.6 per cent) can properly be charged to property. The major fraction of the cost of this operation should properly be chargeable to users on the basis of the suspended solids load.

As shown in Table II (left-hand columns) the approximate allocations made herein result in 17.8 per cent, or $12,500 of the total operation and maintenance costs of $70,500, being chargeable to property and the balance to use.

Summarizing the allocation of the fixed and operation charges:

	Chargeable to			
	Users		Property	
	%	Amount	%	Amount
Fixed charges:				
Intercepting sewers	36.0	$ 12,700	64.0	$22,300
Treatment plant	69.7	52,250	30.3	22,750
Operation and maintenance costs	82.2	58,000	17.8	12,500
Totals and averages	68.1	$122,950	31.9	$57,550

TABLE III.—Allocation and Distribution of Total Annual Revenue Requirements

	Fixed Charges		Oper. and Maint.		Total Annual Charges	
	(%)	($)	(%)	($)	(%)	($)
Chargeable to property	41.0	45,050	17.7	12,500	31.9	57,550
Chargeable to users:						
Total	59.0	64,950	82.3	58,000	68.1	122,950
Volume	23.1	25,410	20.8	14,700	22.2	40,110
Susp. solids	7.2	7,960	34.8	24,500	18.0	32,460
B.O.D.	28.7	31,580	26.7	18,800	27.9	50,380
Total	100.0	110,000	100.0	70,500	100.0	180,500

The amount allocated to property ($57,550) can be distributed as a sewage charge to different classes of property in any one or combinations of methods already mentioned. For purposes of this illustration the ad valorem tax is employed. On the total assessed valuation of $20,000,000 this results in a millage rate of 2.88, or $2.88 per $1,000 of assessed valuation. This, then, is the first part of the sewage rate structure.

It now remains to distribute the user's share of $122,950 among the different classes of users.

Distribution of User's Share (Average Method)

As already mentioned, the construction and operation costs of the various units of a sewage works are influenced differently by the type of load they are called to operate on. Some units, such as the intercepting sewers, pumping stations, and preliminary sedimentation tanks, are principally affected by volume. The oxidizing units are primarily influenced by B.O.D. content and the sludge disposal works by suspended solids. Chlorination is principally affected by chlorine demand, which for simplicity in this illustrative example is assumed to be in proportion to the B.O.D. loading.

Tables I and II illustrate a distribution of the user's share by volume, suspended solids, and B.O.D. It should be pointed out that in this distribution, more so than in the case of the allocation to use and property, a considerable amount of judgment, reinforced by experience, must be brought into play. With the details of a particular situation in mind, however, the distribution is susceptible of relatively close calculation. Thus, if one considers a trickling filter unit with recirculation, the design of the distribution and underdrainage systems at first glance might be considered as affected entirely by volume. However, the quantity of flow recirculated is influenced by the B.O.D. loading, which fact must be considered in the distribution. The cost of the filter bed proper is almost wholly chargeable to B.O.D., as is the cost of recirculation.

The distribution of the user's share of $122,950, as calculated above, results in the following:

Chargeable to volume	$ 40,110
Chargeable to susp. solids	32,460
Chargeable to B.O.D.	50,380
Total	$122,950

The allocation between users and property, and the distribution of the user's share can now be summarized as in Table III and Figure 3.

Determination of Rates and Schedules (Average Method)

The sewage charge to property has already been determined as being 2.88

mills. The rates to users can be calculated as follows:

Chargeable to	Total Amount ($)	Annual Quantities	Unit Rate
Volume	40,110	1,370 m.g.	2.93¢ per 1,000 gal.
Susp. Sol.	32,460	3,647,000 lb.	$0.89 per 100 lb.
B.O.D.	50,380	3,874,000 lb.	$1.40 per 100 lb.

In the illustrative example the allocation and distribution has been calculated approximately, based on certain assumptions. This was necessary for purposes of simplicity, as otherwise the statement of assumed conditions would be undesirably long. In an actual situation certain other factors in addition to those mentioned would be considered. The example, nevertheless, illustrates the basic principles involved. Engineers might differ somewhat in the application of this method, but the committee believes that the principles are so eminently fair that courts and regulatory agencies will approve, even if the details of calculations are not entirely correct or fair.

In the illustration the contribution of sewage by public use has been charged against property. This amounts to between 2.4 and 4.0 per cent of the different parts of the works. A variation in this method suggested by the Joint Committee is based upon the reasoning that there is a public benefit in the form of improved general health and welfare, and in freedom from damage suits, by reason of the existence of the sewage works, and a percentage of cost can properly be charged as a general public benefit. This amount is intangible, but would be small (the Joint Committee report employs 5 per cent in an illustrative example.)

Furthermore, the above are the theoretical rates which would have to be charged to raise the needed annual revenue requirements. In an actual situation they would be made slightly higher to allow for possible non-collections and contingencies, or for discounts if such were to be applied.

Having completed the calculations for the illustration, it is interesting to

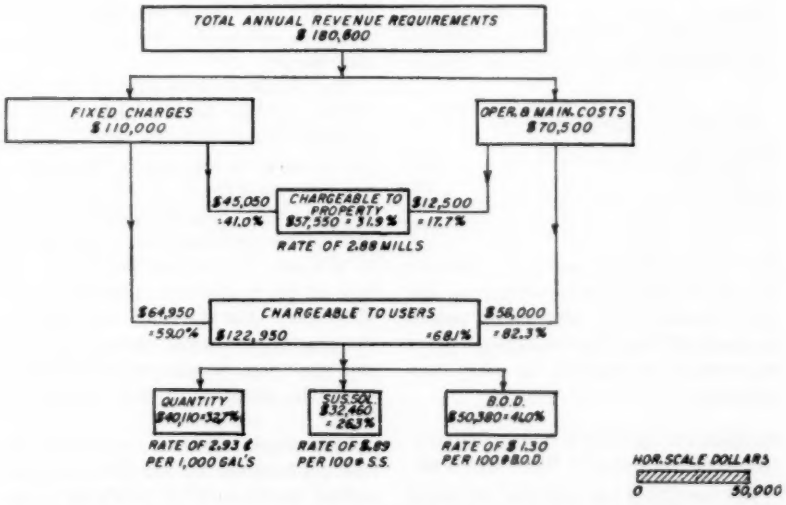

FIGURE 3.—Illustrative example. Allocation and distribution of total annual revenue requirements to users and to properties.

consider in a general way what would happen to the allocation for other sewage works involving differing units and proportions. In the illustration the construction cost of intercepting sewers is a small percentage of the total. In a situation where the sewers constitute a larger percentage of the total construction cost, the amount of the fixed charge allocated to property would increase from the value of 41.0 per cent determined herein. Also, where the degree of treatment is lower than assumed (complete treatment with effluent chlorination) the allocation between users and property and the distribution of the users share to quantity and quality would be materially different.

Depending on the situation, the relative proportions allocated to use and to property might vary materially from the values of 68.1 and 31.9 per cent determined herein. In the usual situation, somewhere between ½ to ¾ of the revenue requirements will be chargeable to users in the early years of a project. From information available to the writer, the results of apportionment made by one engineering office for four municipalities compared with the illustrative example as follows:

Municipality	Percent Chargeable to Public and Property	Use
Decatur, Ill.	37.1	62.9
Winona, Minn.	49.4	50.6
Austin, Minn.	29.1	70.9
Buffalo, N. Y.	48.1	51.9
Illustration	31.9	68.1

The municipalities are quite different in type as related to industrial use and other factors. The illustration results in relatively low allocations to property as compared to most of the other communities.

Modification of User's Share Distribution on Readiness to Serve Principle

The foregoing calculations are based on the average method of distributing the user's share of the annual revenue requirements. In general, this follows the premise that users should pay in proportion to their average use of the system. In other utility rate-making, the tendency is to divide the costs based on two elements of service—the readiness to serve, or demand charge, and the actual use charge based on the quantity of the commodity consumed. The Joint Committee sets up a procedure for doing this. Essentially, the procedure involved is to divide the user's share into capacity costs (those influenced by demand), customer costs (billing and collection), and production costs (in this case pumping and treatment). In this case the three elements of costs are $71,350, $4,500, and $47,100, respectively. The Committee suggests that one-half of the capacity costs plus the customer costs be collected by demand or readiness to serve charges (or minimum bills) and the balance by the use charge. In this case then, the amount to be collected by demand or readiness to serve charges would be $\$71{,}350 \times \frac{1}{2} + \$4{,}500 = \$40{,}180$. The balance of the capacity cost plus the production costs, or $\$71{,}350 \times \frac{1}{2} + \$47{,}100 = \$82{,}770$ would be collected by the commodity or use charge.

The demand or readiness to serve charge might be distributed by a method which includes both volume and strength as reflected by the relative proportions of the fixed charges on construction. The maximum daily demand during the previous year might serve as a basis of this distribution, in the case of the major wet industry under discussion. For the usual contributors, the size of the water meter could be employed as a measure of this demand, as is the practice in the waterworks field.

In determining rates for use, in this case represented by $82,770 per year, several blocks could be established, depending on the sewage quantity and quality. In distributing the rates

among the various blocks the calculations would be made up of two parts. First, the item of $47,100 representing the user's share of the cost of treatment and pumping (usually termed production costs) would be spread uniformly over all users. The amount of $35,670 (or one-half of the fixed charges allocated to use) would, according to the Committee method, be distributed over all of the blocks, with the major portion chargeable to the first block, decreasing progressively in the other blocks. Inasmuch as the details of the assumed system (size and distribution of meters and use) are not available, the complete distribution of the user's share on this basis is not made herein.

For a complete discussion of the procedures involved in such a distribution the reader is invited to review the Joint Committee Report (3) referred to. The underlying principle involved is that service can be provided at less cost per unit to the large user than to the smaller one, and this principle can be followed in distributing the user's share of the cost.

Determination of Annual Charge to Major Wet Industry

By applying the unit rates previously determined to the quantities applicable to the industry under consideration, the following annual charges result:

Property charge	$500,000 at 2.88 mills	= $ 1,440
Volume charge	274,000 thousand gal. at 2.93¢	= 8,030
Susp. solids charge	7,970 hundred lb. at $0.89	= 7,100
B.O.D. charge	15,940 hundred lb. at $1.30	= 20,700
Total		$37,270

Under the Joint Committee method, therefore, this industry which has 2.5 per cent of the total valuation of the community and contributes 20.0, 21.8, and 41.2 per cent of the total volume, the suspended solids, and the B.O.D. loads, respectively, pays 20.6 per cent of the needed total annual revenue of the works.

Comparison of Methods as Applied to the Major Wet Industry

It is interesting to compare the charges which might be assessed against the industry involved in the illustrative example under several of the methods now in use.

Method 1—All charges on general property tax.

$$\$180{,}500 \times \left(\frac{500{,}000}{20{,}000{,}000}, \text{ or } 2.5\%\right) = \$4{,}520$$

Method 2—All charges based on sewage volume (uniform rate).

$$\$180{,}500 \times \left(\frac{274{,}000{,}000}{1{,}370{,}000{,}000}, \text{ or } 20.0\%\right) = \$36{,}100$$

Method 3—All charges based on B.O.D. contribution.

$$\$180{,}500 \times \left(\frac{1{,}594{,}000}{3{,}874{,}000}, \text{ or } 41.2\%\right) = \$74{,}500$$

Method 4—Incremental method. Difference in cost of works to handle all sewage and wastes (including industrial wastes) and the cost of work to handle only domestic sewage. These costs have been estimated approximately as follows:

	Total Incl. Industry	Total Excl. Industry
Construction cost	$2,200,000	$1,852,000
Fixed charges, at 5%	110,000	92,500
Oper. and maint. costs	70,500	63,100
Total annual charges	180,500	155,600
Chargeable to industry	$24,900	

Method 5—Fixed charges on property by taxation; operation and maintenance on volume (uniform rate):

Fixed charges	$110,000	
Oper. and maint. costs	$ 70,500	
Fixed charges	$110,000 × 2.5% =	$ 2,750
Oper. and maint. costs	$ 70,500 × 20% =	14,100
Total		$16,850

A variation of more than 1,600 per cent is observable between the lowest annual charge ($4,510 on property tax) and the highest ($74,500 on B.O.D. contribution). Also, it should be pointed out that the apparent equality of the charges for Method 2 (volume basis) and the Joint Committee method is a coincidence only (because of the assumption made as to volume and strength for this particular industry). As will be seen later, there is no correlation between the volume basis and the Joint Committee method for other types of users and property.

Comparison of Methods of Apportioning on Different Users and Property

The calculations heretofore indicate the effect of different methods of apportionment compared to the Joint Committee method for one particular class of user and property. Because the aim is to secure fairness to all classes, it is essential to ascertain how the different methods affect the usual question of "who pays the bill." Calculations have been made for three other classes of users and properties as follows:

1. A residence having an assessed valuation of $5,000, with an annual use of 108,000 gal. of water, equivalent to 75 g.c.p.d. based on four persons to the family. The B.O.D. load is assumed at 180 lb. per year and the suspended solids load at 225 lb. per year.

2. The major wet industry already described.

3. A major dry industry having the same assessed valuation as the major wet industry ($500,000), but contributing 1,830,000 gal. per year having a B.O.D. load of 1,830 lb. (at 120 p.p.m.) and a suspended solids load of 2,190 lb. (at 145 p.p.m.) annually.

4. A small wet industry having an assessed valuation of $80,000, an annual sewage volume of 36,500,000 gal., an annual B.O.D. load of 304,000 lb. (at 1,000 p.p.m.), and an annual suspended solids load of 253,000 lb. (at 800 p.p.m.)

The results of the calculations by the different methods are shown in Table IV and Figure 4. The wide difference in the charges to various classes of property by the different methods is apparent. Considering first the residential property, the very high charges based on Method 1 (property tax for all charges) are observable. Although somewhat reduced, Methods 2, 4, and 5 result in high charges to the residential user and property. The major dry industry, on the other hand, pays as much as the wet industry if all charges are apportioned on a property valuation basis. It proportionately pays a very small amount if costs are apportioned in accordance with Methods 2, 3, or 4. The small wet industry pays only a small fraction of its fair share of the costs on a general tax basis. On a B.O.D. basis (Method 3) it pays proportionately too great a share of the annual costs.

In a general way it can be stated that when all revenue requirements are raised by a general property tax, the residential owner, the commercial property, and industrial establishments of the dry type pay more than their fair share of the costs. The charges to residential properties as shown in Fig-

ure 4 indicate that the familiar statement, "It's father who pays the bill," becomes a truism in this case. And he might not be concerned if he was employed in a wet industry, and obtained from it as salary the wherewithall to pay his taxes. But if he happened to be employed in a machine or printing shop, he might very well question the fairness of this method. Distributing all of the costs on the strength of sewage places an unfair

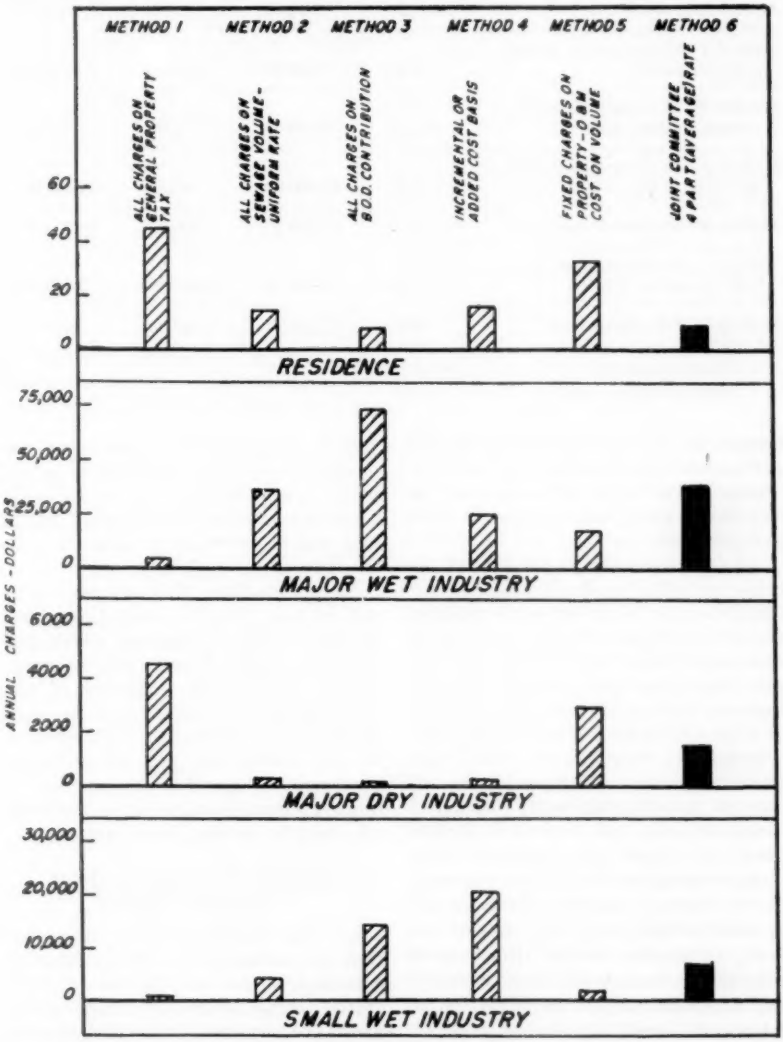

FIGURE 4.—Comparison of various methods of allocating cost on different classes of users and properties.

TABLE IV.—Comparison of Various Methods of Apportioning Costs on Different Classes of Users and Properties

	Residence	Major Wet Industry	Major Dry Industry	Small Wet Industry
Assessed valuation ($)	5,000	500,000	500,000	80,000
Annual sewage (1,000 gal.)	108	274,000	1,830	36,500
Annual B.O.D. (lb.)	180	1,594,000	1,830	304,000
Annual susp. sol. (lb.)	225	797,000	2,190	253,000
Method 1—all charges on general property tax ($)	45.10	4,510.00	4,510.00	723.00
Method 2—all charges on sewage volume, uniform rate	14.22	36,100.00	241.00	4,820.00
Method 3—all charges on B.O.D. contribution ($)	8.40	74,500.00	85.30	14,200.00
Method 4—incremental method	15.30[1]	24,900.00	260.00[1]	20,700.00[2]
Method 5—fixed charges on prop.; O & M costs on volume	33.06	16,850.00	2,844.00	2,320.00
Method 6—J. C. 4-part rate	8.96	37,270.00	1,536.80	7,510.00

[1] Based on volume.
[2] Based on B.O.D. load.

burden on the wet industries in proportion to the benefits and use received. Most other methods result in unfairness to certain classes of users and property.

As approximately 30 per cent of the capacity of the works is provided for future use, it is desirable to consider the effect of the different methods of charging on undeveloped property. For this purpose an undeveloped parcel is assumed having an assessed valuation of $500. With all charges on property (Method 1) this parcel would pay $4.51 annually. However, with all charges made against users (Method 2—volume basis, and Method 3—B.O.D. basis) it would pay nothing, even though almost one-third of the capacity of the works is provided for later use by undeveloped property. Under the Joint Committee method (if assessed valuation is used as the base) it would pay $1.44 annually. As a matter of fairness it should pay a greater share, as it would if area or front footage served as the basis. This may involve certain complications, because an undeveloped property accessible to an existing sewer receives a greater benefit than does another remote parcel, which may not be serviced for some time in the future.

In summarizing this comparison it will be seen that the Joint Committee method results in charges, which, for different classes of users and property, are in between the extremes of the other methods which have been used. Because of its fairness to all concerned in distributing the cost of pollution abatement, it should be accepted by industry, except perhaps by a minority who may be looking for advantage.

Problems in Applying Joint Committee Method

Lest the reader gain the impression that the employment of this method is extremely simple and that no administrative decisions and technical judgment are involved, it is desirable to point out certain problems, some of a minor and others of a major nature,

which present themselves. Some of these are:

1. A decision on how the distribution of the share of the costs allocated to use should be applied to residential and commercial users must be reached. Because, as suggested by the illustrative example, approximately two-thirds of the use share is to be raised by charges based on constituents (B.O.D. and suspended solids), and because it would be impracticable to measure this contribution, it is necessary to develop a way to raise this share of the funds. It being desirable to have a volume schedule of charges uniform in its application to all, the fraction chargeable to strength could be collected by a surcharge on the basic rate for this class of user. As applied to the illustration, there could be added to the volume rate of 2.93¢ per 1,000 gal. a surcharge of 6.05¢ per 1,000 gal. to account for the constituents in average domestic sewage.

Another approach which has been used is to apply to the volume charge the quality charge for sewage of normal characteristics and to make this the basic quantity charge. For the illustration used, this basic charge would be 8.98¢ per 1,000 gal. Then a special industry would be surcharged or discounted on the quality charge, depending on whether its wastes were stronger or weaker than sewage of normal strength. This procedure may be simpler in application, but both produce the same end result.

2. Inasmuch as sewage characteristics are a factor in the rate schedule under the Joint Committee procedure, as they are in other methods which include composition along with volume, it becomes necessary to measure and analyze the various industrial wastes periodically. This costs money. Neglecting the first cost of the measuring devices, the costs of sampling and analysis may be in the range of $40 to $80 per day of sampling. The frequency of sampling has been variously suggested as biennially, annually, semiannually, and quarterly, depending somewhat on the size and type of industry. As one considers the small-sized industries the expenses of sampling may be prohibitive. As an illustration, the cost of quarterly sampling for one day each on our small wet industry contributing 100,000 g.p.d. of waste would be approximately $250, which is more than 3 per cent of the income produced in the form of rates. This industry contributes a waste of 1,000 p.p.m. As the waste from another industry of the same volume contribution approaches the strength of normal sewage (200 p.p.m.), the cost of sampling would be about 15 per cent of the income. Or, considering an industry of the same type as the small wet industry, but contributing only 10,000 g.p.d. of wastes, the cost of sampling on the same basis would be more than 30 per cent of the income.

If one considers an average of two days of sampling a year as necessary, and if a top limit of 5 per cent of the income from a user is set as a reasonable cost of sampling, then it might be proper to exclude from such procedure all contributors whose annual bill is less than 120×20, or $2,400. This suggests two reasonable expedients. The first is to place a minimum limit on quantity, below which sampling will not ordinarily be done. Although not for the same purposes, the Chicago Sanitary District proposed such a limit as 10,000 g.p.d. For the purposes of this procedure it would seem that the limit might be higher (except for an unusual waste), or about 50,000 g.p.d.

Another is to set up in the rate ordinance a strength of sewage to be considered as an industrial waste high enough that it would exclude a number of the lesser contributors. Thus, if a top limit of 400 p.p.m. of either suspended solids or B.O.D. (almost twice the strength of the assumed ordinary domestic sewage) were set as the dividing line, a relatively large number of

industries might be excluded from consideration. An objection, of course, is that this procedure would encourage dilution with cooling, or condenser, or other clean waters to escape the strength provisions of the rate schedule. However, by so doing, the industry would be penalized on the quantity portion of the schedule, although in some cases perhaps not in the same proportion.

Obviously, then, the load in pounds of B.O.D. or suspended solids would be the more exact yardstick. If one employs the two limits considered above of 50,000 g.p.d. and 400 p.p.m. of suspended solids or B.O.D., then the annual load limit which might be excluded would be 60,000 lb. Such an industry would contribute (assuming both suspended solids and B.O.D. were at 400 p.p.m.) $1,850 annually on the user's share of the schedule. Sampling for a single day once a year would amount to about 3 per cent of the income from the industry, which might be considered reasonable.

It should be understood that the limiting values considered above are not suggested for use, but are simply illustrative. The illustration does point up the fact that in a rate ordinance reasonable limits should be set on the quantity and quality of wastes which should be considered in this connection. Otherwise, unreasonable expenditures may be involved in sampling and analysis.

3. A problem very frequently presents itself when the collecting system has already been installed and has been paid for on a property basis (either by tax levy, or special assessment, or both) and many years later the need for intercepting sewers and a treatment plant arises. The Joint Committee method includes such sewers in determining the rate base. The amount chargeable to this unit should be segregated and considered separately in determining the allocation of charges. This difficulty is caused by early unfair practice, and should be corrected on a fair basis as far as feasible.

4. It is recognized that municipal sewage systems have a very poor load factor, as variations in quality have somewhat the same pattern as variations in quantity. Certain industries may add to the peak loads, whereas others, either inherently or by controlled storage, may improve the load factor. It is conceivable that the discharge from an industry can be so regulated by storage that it adds nothing appreciably to the designed capacity of the works, and little to the operation costs of certain parts of the plant. In fairness, some adjustment in the rates should be accorded this industry when compared to one which adds its peaks, either normal or abnormal, to those of the balance of the system. Conversely, the industry which adds unreasonably to the peaks should be required to provide storage or should pay a higher rate.

5. It is also recognized that a great number of factors of influencing or controlling importance are involved in these procedures. The Committee report of the California Sewage Works Association (38) discusses some of these. Sometimes the governing body will not feel that it can apply the principles set forth in the Joint Committee method, what with already high property taxes and attempts to broaden the tax base. Nevertheless, the results of the Joint Committee method should be recognized as a point of departure, so that when the practicalities of a local situation influence otherwise, administrative officials will be advised of just how far they are departing from a fair procedure.

6. Although this problem applies equally to other types of rates and rate structures, it should be recognized that, to approach fairness, the allocation and distribution made by the Joint Committee procedures, because they change with time, should be reviewed periodically. Considering just one ele-

ment of the allocation (for example the provisions for the future), it has already been pointed out that this proportion becomes less as the continued growth of the community approaches the capacity of the works. The frequency of review would depend on the rate of development of the community and its component parts, and intervals of 3 to 10 years have been suggested. However, once the basic facts have been developed this becomes a relatively simple problem.

Use of Formulas for Determining Charges to Industry

In the past five years, more and more references are found in the literature to the use of formulas designed to charge industry for the special service it receives. Where an allocation of costs between users and property is made in advance (as in the case of Buffalo, N. Y.) and a special formula is applied to the user's share which measures the use and benefits, then fairness is possible.

Engineers are inclined to accept a formula as a mathematical expression of facts. Obviously, what may be so for the particular case for which it was derived may be an invalid expression when applied to others. Furthermore, the formula may not be factual at all. The author deprecates the continued advocacy of this type of rate making. Formulas are too easily seized upon by the uninitiated, who, with a false sense of security, apply them with disastrous results, insofar as fairness is concerned.

In an attempt to illustrate this, the author has applied the Wright (27) formula to the example previously considered. Incidentally, this formula has been applied by at least one large city (29)(45)(46) (with some reasonable modifications, however) and one small city (28) which have come to the author's attention. By applying the formula as presented, as one city (28) has done, the charge to the illustrative major wet industry would be $75,300. By modifying it to take into account the differences in strength between the illustration and those which the formulator assumed, the charge to the wet industry becomes $69,300. This compares with charges of approximately $37,000 by the Joint Committee method. It approaches those which the industry would pay on a proportional B.O.D. basis. And considering the method of development, it should be so, because the formula is based on the assumption that all costs of treatment are proportional to the strength of the sewage. Many of them are not, as witness the fact that collection, pumping, and sedimentation costs are based almost wholly on volume and not on strength.

Summary and Conclusions

1. A number of widely varying methods of determining charges for the handling of industrial wastes are employed in United States municipalities.

2. Most of the methods employed place too great a burden on property on the one hand or users on the other and, therefore, result in unfairness to certain classes of properties and users.

3. A sincere desire has been shown by administrators and engineers of municipalities and industries to achieve fairness.

4. The Joint Committee procedure presents a method of achieving fairness in the allocation of costs between users and properties in proportion to the use of, and the benefits received from, the sewage works.

5. Even with the adoption of a method which fairly allocates the costs, a number of factors of influencing or controlling importance must be considered in each local situation.

6. The more general employment of the Joint Committee method, admittedly not as yet adequately tested in all procedural details, will result in improvements in its application.

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CORRECTION

In the paper on "Color in Industrial Wastes. II. Determination by Filterphotometric Method" (THIS JOURNAL, 23, 10, 1291; Oct., 1951), the sentence beginning on page 1295, line 15, should read: "The total color contribution factors for the Y and Z transmission values were calculated to be, respectively, 0.316 and 0.374."

DETERMINATION OF PHENOLS BY THE AMINO-ANTIPYRINE METHOD *

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Recently, pilot plant studies were made on the chemical oxidation of small amounts of phenol in coke plant ammonia still waste. In these studies there was a need for a rapid method for the determination of phenol. A rapid method would provide the information required as a guide for subsequent treatments and would make possible the analysis of a large number of samples. From a review of the literature, it was believed that a method based on the reaction of 4-aminoantipyrine reagent with phenol might be readily applied to this problem. The purpose of the present paper is to present additional information on the use of 4-aminoantipyrine as a reagent for the simple and rapid determination of phenols.

In 1943 Emerson (3) reported that in alkaline solutions phenols react with 4-aminoantipyrine in the presence of oxidizing agents to form intensely colored compounds. He also pointed out the structural requirements that must be met by the phenolic compounds if the color reaction is to take place and listed a large number of organic compounds and their reactions with 4-aminoantipyrine.

The aminoantipyrine reaction was used by Gottlieb and Marsh (6) as the basis for the determination of certain preservatives, germicides, and other similar phenolic compounds. These same authors also presented absorption curves of the color produced with the various compounds, in addition to a detailed procedure.

Martin (7) applied this method to the determination of phenol in salt brine solutions without preliminary purification. However, he recommended the use of filtration and distillation for cloudy and colored solutions.

Special Solutions and Equipment

The special solutions and equipment needed in the determination of phenol by the aminoantipyrine method include:

1. A filter photometer, such as the Klett-Summerson or the Kromatrol photometer, using a filter with maximum transmittancy at approximately 510 mμ. and having a cylindrical cell with a light path of approximately 1 cm.
2. A pH meter.
3. Pyrex all-glass distillation apparatus (No. 3,360), consisting of a 500-ml. distilling flask and a Graham condenser.
4. 4-aminoantipyrine, 2 per cent (water solution of powder as received from Winthrop-Stearns, Inc.)
5. Potassium ferricyanide, 8 per cent water solution.
6. Standard phenol solution (100 p.p.m.) containing 0.100 g. white crystals of phenol (analytical reagent grade) diluted to 1 liter.

Experimental Procedure

The experimental procedure of the method was carried out as follows:

Transfer a definite amount (75 ml. or less) of a solution containing a maximum of 500 micrograms of phenol

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to a 250-ml. beaker. If necessary, dilute to 75 ml. and adjust the solution to pH 10.5 with dilute (1:9) NH_4OH. Transfer this solution to a 100-ml. volumetric flask and dilute to the mark with distilled water.

Add 2.0 ml. of 4-aminoantipyrine solution and mix well. Rinse the photometer absorption cell with approximately 5 ml. of the solution. Then add approximately 10 ml. to the cell and obtain a reference reading on this solution. This value is deducted from the total reading obtained after color development. Now add 2.0 ml. of the potassium ferricyanide solution and mix well. Rinse the cell and then obtain a reading on the colored solution.

Quantities of 4-Aminoantipyrine and Potassium Ferricyanide

In investigating the variables of this procedure, a study was made of the amounts of 4-aminoantipyrine (AAP) and of potassium ferricyanide required to give the maximum color density. Using as a guide the quantities of reagents given by Gottlieb and Marsh (6), investigation showed that the maximum color density is obtained when 2.0 ml. of each reagent is used for 100 ml. of solution containing up to 500 micrograms of phenol. Figure 1 shows the effect of varying amounts of these reagents upon the density of the color formed.

Effect of pH upon Color Formation

Emerson (3) stated that an intense color is formed due to the reaction products of 4-aminoantipyrine with phenols, provided the alkalinity is high enough to prevent the formation of antipyrine red. In their work Gottlieb and Marsh (6) recommended an adjustment to pH 10.4 to 10.6.

It appeared advisable to investigate the effect of pH on the color formation. To accomplish this, readings were obtained at various pH levels on reagent blanks and also on solutions containing 500 micrograms of phenol. Figure 2 shows the color densities produced on these solutions at the various pH levels. From these curves it is seen that the antipyrine red color of the reagent itself forms at pH 7.5 to 8.0 and lower. When the alkalinity is greater than pH 8.0, the color density remains constant until a pH of 10.0 is reached. Beyond this point the color density decreases with further increase in alkalinity. Above pH 8.0 the reagent blanks are very low.

At this point, it must be mentioned that the addition of the reagents affects the final pH obtained. Individually, the 4-aminoantipyrine solution or the potassium ferricyanide solution has almost no effect on the pH of the solution. However, it was observed that when these reagents are both added to the same solution an appreciable drop

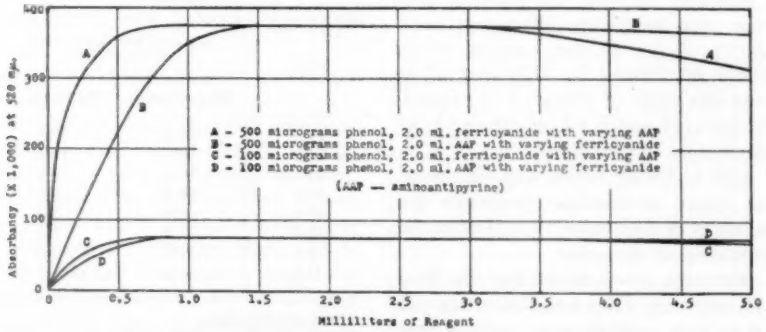

FIGURE 1.—Reagent requirements (for 100-ml. volume).

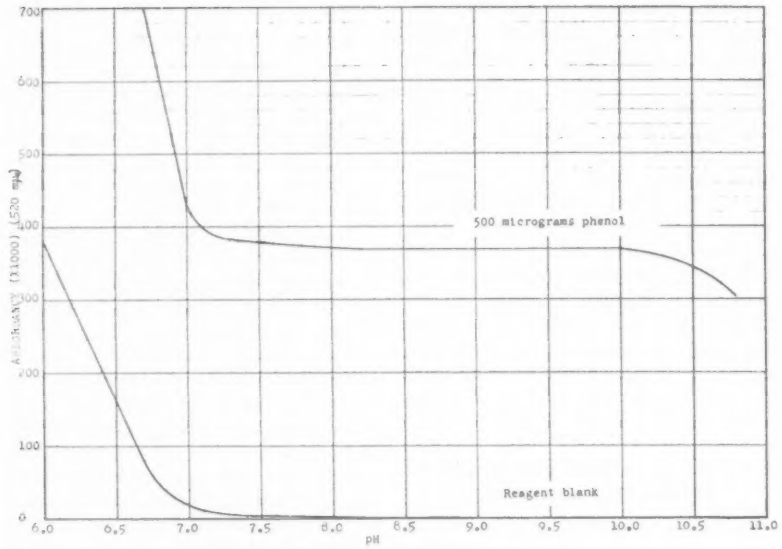

FIGURE 2.—Effect of pH on color intensity.

in the pH of the solution results. Because the pH of the solution is adjusted before addition of the reagents, the attainment of the permissible final pH is a matter of trial and error. It was also observed that the presence of sufficient ammonium chloride greatly lessened this drop in pH, probably due to the slight buffering action of the ammonium chloride. Table I shows the effect of ammonium chloride upon the stability of the pH. The amount of ammonium chloride necessary to provide this stabilizing effect was arbitrarily chosen as that amount which would be formed by additions of at least one drop of dilute (1:1) hydrochloric acid and 5 ml. of dilute (1:9) ammonium hydroxide.

This buffering action and the broad pH range permissible eliminates the necessity of measuring the pH after the formation of the color.

Although it was shown that the final pH may vary from approximately pH 8.0 to 10.0, good practice dictates that closer limits be placed on the pH range. The optimum pH range for other phenolic compounds may not be as broad as the pH range for phenol itself. This is indicated by the observation of Gottlieb and Marsh (6) that a variation of 0.5 pH unit caused deviations in density and stability of the color of certain phenols.

The initial pH should be adjusted near the upper limit of the pH range

TABLE I.—Buffering Effect of Ammonium Chloride

Initial pH	pH After Addition of AAP[1] and Ferricyanide	
	NH_4Cl Present[2]	NH_4Cl Absent
11.0	10.8	10.5
10.8	10.6	10.3
10.5	10.2	9.7
10.4	10.2	9.6
10.1	9.9	8.5
10.0	9.8	7.2
9.9	9.8	6.6
9.6	9.5	6.2

[1] Aminoantipyrine.
[2] Introduced by addition of 1 drop of dilute (1:1) HCl and 5 ml. of dilute (1:9) NH_4OH.

of 8.0 to 10.0 for two reasons. First, the initial pH should be high because there is a tendency for the pH to drop after addition of 4-aminoantipyrine and potassium ferricyanide (this tendency, of course, is reduced when sufficient ammonium chloride is present). Secondly, it is believed that organic compounds, such as aromatic amines, will interfere to a lesser degree at higher pH levels. For example, the interference of aniline has been shown to be less at higher pH levels in investigations made by Ettinger, Ruchhoft, and Lishka (5). However, because their observations were made on chloroform extractions of the colored compounds, the same relationship may not necessarily be true for aqueous solutions.

It is recommended that the solution be adjusted to an initial pH of about 9.8 (9.6 to 10.0). The final pH would then be approximately 9.5 to 9.9 under the prescribed conditions; that is, with ammonium chloride present.

Distillation of Samples

If no interfering compounds are present in the sample, it is simpler and faster to analyze for phenols by developing the color without distillation of the sample. The practice, previously described, of obtaining a reference reading prior to the addition of the potassium ferricyanide permits the use of slightly cloudy or colored solutions, especially if the phenol content is sufficiently high to permit the use of a small sample.

However, distillation is required on samples that are intensely colored, very turbid, or contain interfering inorganic or organic compounds. This distillation is performed in a pyrex all-glass distillation apparatus after addition of copper sulfate and adjustment with phosphoric acid to approximately pH 4. The procedure is similar to that used in the Gibbs method (1). A detailed discussion of the distillation technique is given by Beshtegoor, Greene, and Stenger (2) and Ettinger and Kroner (4).

TABLE II.—Distillation of Sample (5 to 400 p.p.m. Phenol)

10-ml. Portion of Distillate	% Sample Distilled[1]	Approximate % Phenol Distilled
1st	9	18
2nd	18	34
3rd	27	49
4th	36	62
5th	46	72
6th	55	81
7th	64	88
8th	73	93
9th	82	96
10th	91	98

[1] 110-ml. sample.

The procedure used in connection with the 4-aminoantipyrine method consists of distilling a 110-ml. sample, which has been adjusted as stated above, and collecting 100 ml. of distillate. Analyses made on the separate fractions of the distillate indicate that the amount of phenol distilled is not proportional to the amount of sample distilled. Table II shows the percentage of phenol distilled in successive 10-ml. fractions.

When 100 ml. of distillate are collected, 98 per cent of the total phenol has been distilled. To obtain the same concentration of phenol in the distillate as was present in the sample, the value of phenol obtained on the distillate must be multiplied by 0.93, or $10/11 \div 0.98$.

Interfering Compounds

Strong oxidizing or reducing agents must be absent. Although sulfites interfere, fairly large amounts of sulfide (as much as 200 to 300 p.p.m.) have little effect. Metallic ions that react with potassium ferricyanide also interfere. In such cases, it is necessary either to employ a prior distillation or to substitute ammonium persulfate for the ferricyanide. However, the color developed with persulfate is slower to form and is less stable. Aromatic amines form a color under the same

conditions and quinone interferes to a slight degree.

The various phenolic compounds react with 4-aminoantipyrine and potassium ferricyanide to produce colors of varying densities. Phenol, itself, gives the greatest density. Table III lists the relative densities of the colors produced by various organic compounds as compared to phenol.

Because phenolic compounds other than phenol itself produce colors of lesser density than does phenol, a minimum value will always be obtained. In others words, in a mixture of phenols the value obtained will always be lower than the actual amount of phenols present.

All the compounds listed in Table III give consistent readings within the range of pH 8.0 to 10.0, except thymol, which has its maximum color density at approximately pH 9.7 and decreases in density when the pH is greater or less (approximately 20 per cent less in density at pH 8.2).

Recommended Procedure

Transfer 110 ml. of the sample to a 250-ml. beaker and add 1 ml. of 10 per cent copper sulfate. Adjust the solution to a pH of approximately 4.0 with phosphoric acid, using a pH meter or methyl orange indicator and maintaining the volume at less than 115 ml. Transfer the solution to a 500-ml. distilling flask with ground glass joint and connect to a condenser (such as a Graham condenser). Collect 100 ml. of the distillate in a 100-ml. volumetric flask and mix.

TABLE III.—Color Densities Obtained with Various Organic Compounds

Compound	Density Compared to Phenol[1] (%)
Phenol	100
o-cresol	74
m-cresol	69
p-cresol	3
8-hydroxyquinoline	52
Thymol	33
2,4-dinitrophenol	No color
Hydroquinone	3[2]
Quinone	4[2]

[1] Readings taken with 520-mμ. filter within 1 min. after addition of the potassium ferricyanide.

[2] With quinone and hydroquinone a color is formed after addition of ammonia and after addition of 4-aminoantipyrine. The figures given refer only to the color formed after addition of the potassium ferricyanide.

Pipette a suitably sized aliquot of the distillate (or of the original solution if distillation is not employed) into a 250-ml. beaker and add distilled water to give a total volume of 75 ml. This aliquot should contain less than 500 micrograms and preferably more than 100 micrograms of phenol. Add 1 drop of dilute (1:1) hydrochloric acid and 5 ml. of dilute (1:9) ammonium hydroxide. Then, by further additions of acid or base, adjust the pH to 9.8 (9.6 to 10.0) using a pH meter.

Transfer the solution to a 100-ml. volumetric flask, rinsing the beaker a few times with distilled water. Dilute to 100 ml., mix, add 2.0 ml. of 4-aminoantipyrine solution and again mix. After rinsing the photometer absorption cell twice with water and once with a portion of the solution, add a sufficient quantity of the solution to the cell and obtain a reference reading on the photometer. Add 2.0 ml. of potassium ferricyanide to the remainder of the solution and mix. Rinse the absorption cell with a portion of the solution, add a sufficient quantity of the colored solution to the cell, and obtain the total reading on the photometer.

From a calibration curve determine the micrograms, γ, of phenol equivalent to the reference reading and to the total reading. Calibration curves are prepared by transferring varying amounts of the standard phenol solution to a beaker and proceeding exactly as directed in the method. Figure 3 shows calibration curves obtained

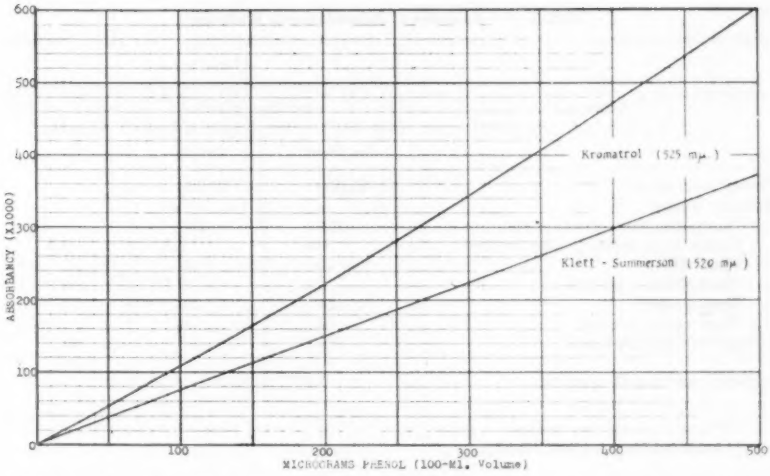

FIGURE 3.—Calibration curves for phenol standards on two types of photometers.

on the Klett-Summerson and on the Kromatrol photometers.

If a straight-line calibration curve is obtained, as is the case when using the Klett-Summerson photometer, it is convenient to use a factor. If the calibration curve is not a straight line, a conversion table may be prepared from the curve. No correction is ordinarily made for a blank on the reagents, as the blank is so low (1 to 2 units) as to be of no significance.

TABLE IV.—Analyses of Coke Plant Samples

Sample	Phenol (p.p.m.)		
	4-Aminoantipyrine		Gibbs
	Not Distilled	Distilled	
Ammonia still feed[1]	2,280 2,430	2,170 2,150	2,420 2,460
Ammonia still waste	168	58	58
Ammonia still waste, treated	94	39	37
	29	15	16
	1.6	1.2	—
	—	0.22	0.15
	—	0.26	0.23
Purification liquor	508	563	—
Light oil separator	162	160	—
Total effluent	0.2	0.2	—
River water	<0.1	<0.1	<0.05

[1] Duplicate samples.

Calculations

Without Distillation

p.p.m. phenol = (γ tot. phenol − γ phenol equiv. in ref. sol.) ÷ ml. of sample

or

p.p.m. phenol = (tot. reading − ref. reading) × factor ÷ ml. of sample

With Distillation

p.p.m. phenol = (γ tot. phenol − γ phenol equiv. in ref. sol.) × 0.93 ÷ ml. of sample

or

p.p.m. phenol = (tot. reading − ref. reading) × factor × 0.93 ÷ ml. of sample

Analysis of Miscellaneous Materials

The analyses of several types of material are listed in Tables IV and V. There is fairly good agreement between the values obtained by the 4-aminoantipyrine method and the values obtained by Gibbs method. However, when distillation is omitted, the aminoantipyrine values are higher on some samples, probably due to the presence of interfering organic compounds.

TABLE V.—Analyses of Miscellaneous Materials

Sample	Phenol (p.p.m.)		
	4-Aminoantipyrine		Gibbs
	Not Distilled	Distilled	
Phenol resin waste	24,000	16,000	—
Refinery waste:			
Composite from cracking unit	220	249	—
Comp. from cracking unit, treated	0.4	2.5	2.5
Final effluent	28	30	37
Final effluent, treated	0.5	0.2	0.1
Trap waste	24	26	—
Trap waste, treated	10	10	—
Formaldehyde resin waste	81	77	80
	—	—	78[1]
Standard solution, 0.10 p.p.m.	0.11[2]	—	—

[1] Bromine absorption method.
[2] Corrected for a reagent blank.

Sensitivity

The sensitivity of this method is approximately 0.1 p.p.m. In analyzing a standard solution containing 0.1 p.p.m. phenol, values obtained were 0.11, 0.11, and 0.11 (corrected for reagent blank).

Summary

An investigation of the aminoantipyrine-phenol color reaction has shown it to be applicable to the determination of phenol in coke plant wastes. Brief tests indicate that this method may also be used on other types of phenol-containing wastes.

The effects of reagent concentration and pH have been investigated and the optimum conditions determined.

The method can frequently be used without the necessity of a preliminary distillation, and consequently is very rapid. A single determination may be made in about 10 min. When interfering substances are present and prior distillation is required, the time required for a single determination is increased to 45 min.

Acknowledgment

The author wishes to express his appreciation to M. L. Riehl, formerly of the Ohio Department of Health, for his cooperation in this study.

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SEDIMENTATION AND FLOCCULATION EQUIPMENT FOR TREATMENT OF INDUSTRIAL WASTES *

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This paper briefly reviews some applications which have been made of floeculation and sedimentation equipment and procedures in the treatment of various industrial wastes. Case histories are presented of waste treatment in several typical industrial fields in the hope that this information will be helpful to those faced with similar problems. Also, the facts presented may serve as a guide to the application of flocculation and sedimentation equipment in waste treatment problems heretofore not approached by these methods.

Many constituents of industrial wastes can be removed by chemical precipitation under the proper controlled conditions. The first step, naturally, consists of thorough mixing of the treating chemical with the waste. This mixing has been accomplished by introducing the chemical in a pipeline, flume, baffled chamber, or similar point in the system where turbulence is present. More positive control can be maintained, regardless of fluctuations in the quantity of the waste, through the use of mechanical mixing devices. Such devices normally have a retention time of 0.5 to 5 min.

After the addition of chemicals, a flocculation period of 30 to 60 min. is normally allowed. During this period the waste is slowly agitated to provide contact between the individual precipitated particles to allow agglomeration of these particles into a well-conditioned floc with suitable settling characteristics. A Vorti-Floc (Figure 1) is used in this service. The impeller can normally be varied in speed between 5 and 15 r.p.m. The optimum speed for flocculation should be determined in the field. The mixing unit can be of essentially the same design but with a higher speed, constant speed impeller.

There are a variety of sedimentation basin designs, the two basic types being scraper flights on a continuous chain powered by sprockets on horizontal shafts and scraper mechanisms rotated by a vertical shaft, as shown in Figure 2.

Trend Toward Integrated Units

Within recent years there has been a definite trend, away from the construction of these three basic steps as individual units, to the integration of the mixing, flocculation, and clarification steps in a single compact unit. This trend has been largely dictated by the improvements made in this "high-rate" type of unit, the superior results that can be obtained, the reduced installed cost of such units, and the savings afforded in the space requirement.

The "high-rate" units can again be divided into two basic classifications. One consists of the so-called "sludge blanket" unit, in which the chemicals are mixed in a central compartment from whence they pass downward and percolate upward through a suspension of precipitated solids, or sludge blanket. The second type of unit utilizes mixing in a primary zone, transfer of this mixture of incoming wastes,

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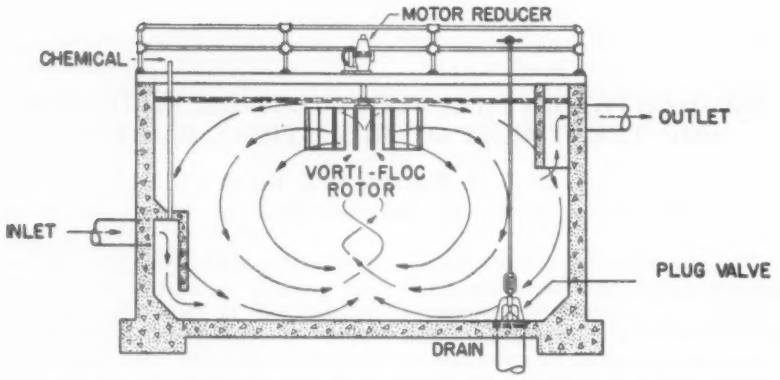

FIGURE 1.—Vorti-Floc unit for flocculation of chemically treated wastes.

chemicals, and previously formed precipitates upward by means of a low-lift impeller to a secondary flocculation zone, discharge from this zone as a downwardly moving slurry in such a manner that the clarified liquor is "squeezed out" of the moving slurry while the slurry is returned to the primary mixing zone to serve as nuclei for the precipitation of new solids. Such units can be provided with concentrator areas for removal of the solids formed at a rate necessary to maintain a solids equilibrium in the unit, or, if the solids are quite voluminous, it is preferable to provide solids removal by means of bottom-scraping mechanisms. The detention time of such units will vary with the particular waste involved, but will normally range between a minimum of 1 hr. and a maximum of 4 hr. It should be noted that this time includes mixing, flocculation, and clarification. The retention time is, therefore, appreciably less than in a system involving individual units where 5 min. may be utilized for mixing, 30 min. for flocculation, and a minimum of 2 hr. to a maximum of 6 hr. for sedimentation.

Figure 3 illustrates the flow pattern in the Accelator. This is the unit utilizing slurry recirculation, which is applicable when relatively low sludge volumes are involved and when the sludge compacts readily. The solids in this case are removed in the concentrator areas shown. Figure 4 is a schematic drawing of the Cyclator mechanism,

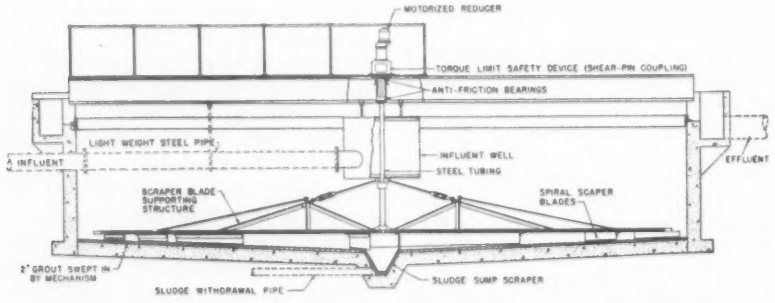

FIGURE 2.—Typical sedimentation basin with rotating scraper mechanism.

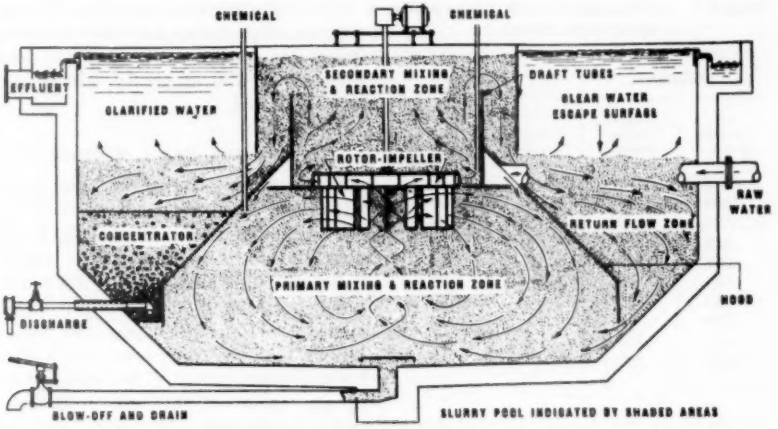

FIGURE 3.—Flow pattern in Accelator unit.

which again involves slurry recirculation. In this case, however, the solids are removed by the bottom-scraping mechanism; therefore, this unit is more applicable for wastes which will produce voluminous sludges requiring additional thickening prior to discharge. In either of these units the recirculation can be maintained by means of a gas lift, making them very applicable in cases where the introduction of air or CO_2 is beneficial, such as the precipitation of lime from tanning wastes as $CaCO_3$ by the addition of CO_2.

The equipment involved for flocculation and clarification of industrial wastes will not vary to any great extent from that utilized in the treatment of water for normal industrial uses, with the possible exception of the use of special modifications, as outlined previously, for handling some of the voluminous sludges produced. However, in many cases special treatment must be provided prior to the flocculation and clarification unit, such as the reduction of chrome wastes and oxidation of cyanides.

Floc Formation Important

No clarification unit will do an effective job unless a well-formed floc particle of suitable density can be obtained. Because of this, a thorough study is usually required to determine exactly what conditions will produce

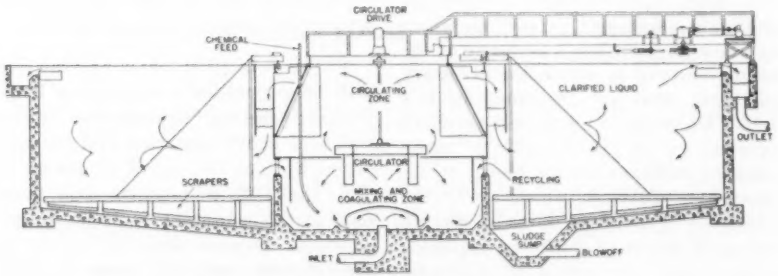

FIGURE 4.—Flow pattern of Cyclator unit.

TABLE I.—Oil Removal from Refinery Waste by Softener Sludge

Influent		Effluent	
Oil Content (p.p.m.)	Oil-Free Solids (p.p.m.)	Oil Content (p.p.m.)	Oil-Free Solids (p.p.m.)
186	141	5	2
390	425	30	20
322	150	16	36
118	155	4	20
662	294	20	24
426	88	8	38
533	142	19	55
330	17	2	10
274	133	15	35
2,400	208	16	41

the ultimate floc formation and what, if any, coagulating materials are most suitable. Alum or alum and activated silica are frequently effective, and ferrous or ferric salts are frequently indicated. In most cases, the dosages involved may be much higher than those normally encountered in industrial water treatment. Lime alone is effective in many cases, due to the precipitation of metallic salts or of calcium salts of organic materials present. Magnesium compounds, such as epsom salts, are particularly effective if the waste has a high pH. In cases where an adsorbent is helpful, calcium carbonate, either in the form of water-softening sludge or as ground limestone, is effective. Such a material is particularly effective for oil absorption or for the removal of colloidal organic materials. This treatment is particularly applicable when water-softening sludges are available, because of the savings which can be afforded when a majority of the solids required to obtain the necessary solids-oil ratio are furnished in this way. Kalinske (1) reported excellent removal of oil in a refinery waste utilizing softener sludge alone, as indicated in Table I, which shows the negligible effect of shock loads. Should a greater degree of clarity be required, a few grains per gallon of coagulant will polish the effluent.

The following case histories of industrial waste problems and their solutions illustrate methods which have been utilized, as well as results which have been obtained.

Asbestos Paper Wastes

White waters discharged from paper mills can be effectively clarified by flocculation and separation of the fibers, with the addition of suitable coagullants, affording suspended solids reductions in excess of 95 per cent. Treatment of white water has the added benefit that the costs are compensated for to a great extent, if not completely, by the value of the recovered fibers and the reduction in the plant make-up water requirement by recirculation of the clarified effluent in the plant system.

Extensive pilot plant tests were conducted in late 1949 on the flocculation and clarification of asbestos board and asbestos paper white water wastes at the Norristown Magnesia and Asbestos Co. plant at Norristown, Pa. After the evaluation of several methods of treatment to reduce the suspended solids and B.O.D. in the white water formerly discharged to the stream, flocculation and clarification under proper conditions proved to be the answer. For this phase of the investigation, a model Accelator 5 ft. in dia. with a 2.5-ft. sidewater depth and having a total volume of 360 gal. was used.

The various types of fibers encountered in this plant can be roughly classified by the chemical treatment to which they respond best, as follows:

1. The 8- to 16-lb. paper and heavier mill board products, containing long-fibered asbestos, agglomerate under sufficient gentle agitation and recirculation without the use of chemicals.

2. The 5- to 6-lb. papers and those used in the manufacture of insulation products, because they are made of short-fibered stock and scrap material and tend to be high in talc, require

TABLE II.—Pilot Plant Results on Asbestos Paper Wastes

Type of Paper	Susp. Solids			Turbidity			Chemicals Used
	Raw (p.p.m.)	Eff. (p.p.m.)	Red. (%)	Raw (p.p.m.)	Eff. (p.p.m.)	Red. (%)	
12-lb.	1,600	22	98.6	390	30	92.4	None
8-lb. and ½-in. carbon black	1,088	22	98.1	340	25	92.7	None
5½- to 8-lb.[1]	2,132	102	95.3	650	90	86.2	4 gr. per gal. alum
10- to 12-lb.[2]	2,300	41	98.3	600	40	93.4	4 gr. per gal. alum
5½- to 8-lb.[1]	2,108	18	99.1	750	15	98.0	10 gr. per gal. alum 15 p.p.m. silica

[1] Manufacturing grade.
[2] Commercial grade.

the addition of alum or alum and activated silica.

3. Special products having additives of carbon black or silica powders require some alum dosage.

4. Wool felt products require alum in proportion to the quantity of short-fibered asbestos stock or scrap added to the stock.

This particular waste problem is of particular interest because, in addition to having the results of the pilot plant tests (Table II), some information is available on the operation of the 45-ft. diameter Cyclator, having a capacity of 1,250 g.p.m., installed as a result of these tests. The treatment, when the unit was operating at 800 to 1,200 g.p.m., resulted in the same high degree of clarification (Table III) in full-scale operation as obtained in the pilot plant studies.

The underflow from the Cyclator is being re-used as stock in the mill and the percentage of solids by weight is controlled between 1.5 and 2.5 per cent to conform with the stock concentrations carried in the plant. Test runs show that solids concentrations as high as 6 per cent can be maintained in the underflow if desired. On an average, the suspended solids load discharged to the stream is being reduced by 10,000 to 12,000 lb. per day. The unit has proven to be quite capable of taking appreciable shock loads without upset. These shocks are introduced when beaters are dumped without warning; at such times the suspended solids in the influent to the unit may be increased by 200 to 300 per cent.

Cannery Wastes

The treatment of cannery wastes has been the object of extensive study by

TABLE III.—Cyclator Operation Results on Asbestos Paper Wastes

Type of Paper	Susp. Solids			Turbidity			Chemicals Used
	Raw (p.p.m.)	Eff. (p.p.m.)	Red. (%)	Raw (p.p.m.)	Eff. (p.p.m.)	Red. (%)	
6-lb. crimp and 10-lb. roofing	1,020	6	99.5	600	8	98.6	10 gr. per gal. alum 10 p.p.m. act. silica
10-lb. roofing and $\frac{1}{16}$-in. millboard	514	28.5	94.5	250	18	92.8	7 gr. per gal. alum 10 p.p.m. act. silica
10-lb. roofing and 9½-lb. wax	1,240	36.5	97.2	600	40	93.4	7 gr. per gal. alum 10 p.p.m. act. silica

a number of persons and agencies. An Accelator is being utilized by the Searle Co. of Hollywood, Fla., for primary chemical treatment of blanching waters and rinse water from the processing of green, navy, pea, lima, and red kidney beans. In this instance, the wastes are first passed through a rotary screen for removal of the coarser solids. In general, these solids are light, they do not settle well, and if allowed to enter the later stages of treatment they would float and form a scum. In fact, the plant operator now reports that the efficiency of the treatment plant is definitely affected by the efficiency of the screening operation. After screening, the wastes are introduced to the Accelator along with alum and lime. Over a period of two months of operation the alum requirement has ranged between 8 and 12 grains per gallon, with sufficient lime being added to maintain the pH in a range of 6.9 to 7.2. The lime requirement averages 8 to 10 grains per gallon. Coagulation has been good and the effluent from the unit has been clear. No quantitative data are available on the suspended solids in the effluent, except those obtained in an Imhoff cone, which indicate that the suspended solids are consistently below 0.01 per cent by volume.

The B.O.D. reduction over one month of operation on green bean wastes shows an average of 54 per cent and a median, also, of 54 per cent. The B.O.D. in the raw wastes during this period averaged 398 p.p.m. It is interesting to note that this figure is appreciably in excess of the 5-day B.O.D. figures (200 p.p.m.) given in most literature. One would expect that this discrepancy is due to the more modern or modified canning practices utilized. B.O.D.'s in the raw wastes as high as 2,300 to 2,500 p.p.m. are encountered when processing dry kidney beans, and values of 1,700 to 1,900 p.p.m. when dry navy beans are being canned. The wastes dumped from the blancher will have a B.O.D. content as high as 9,000 to 10,000 p.p.m. when processing dry beans, but, of course, the rinse waters provide a dilution factor and it is evident that an equalization tank, provided with a small amount of aeration to prevent septicity, would be desirable in most instances. Extensive data are not available on the B.O.D. reduction obtained with these higher strength wastes, but a spot check during navy bean processing gave a B.O.D. reduction of 55 per cent when the influent B.O.D. was 2,780 p.p.m.

The temperature of the influent waste ranges from 85° to 95°F. and the fact that 90 per cent of the time there is no odor in the Accelator effluent, while during the balance of the time there may be a very slight odor, attests to the work being done by the unit. Here is an instance where it would be advantageous to feed water-softening sludge or ground $CaCO_3$ as an adsorbent.

Oil Wastes

Waste waters containing oil can be divided into two rough classifications: a) wastes containing mainly free oils, such as are encountered in oil refineries, with perhaps some oil present in an emulsified form; and b) true soluble oils, such as the cutting oils and coolants used in metal finishing processes.

The refinery waste problem will usually involve more than oil removal alone. Accelator pilot plant studies have been underway for more than a year at a midwestern refinery to determine the best methods to obtain maximum suspended solids, B.O.D., chemical oxygen consumed, odor, and oil reductions. These wastes have first passed through gravity separators of A.P.I. design, which remove a major portion of the free oil and two of the

resulting discharges have the following average characteristics:

Discharge	Turbidity (p.p.m.)	Susp. Sol. (p.p.m.)	Oil (p.p.m.)	Oxygen Consumed (p.p.m.)	B.O.D. (p.p.m.)	Odor (no.)
A	525	60	100	1,170	280	36,000
B	220	40	155	130	90	185,000

Table IV, for the period Oct. 10 to Nov. 9, 1950, is a tabulation of the tests, per cent reductions obtained, and conclusions when treating discharge A. The results are averages of samples taken continuously by an automatic sampler.

Table V, for the period Jan. 17 to Apr. 3, 1951, gives comparable information on the treatment of discharge B. Perhaps one of the most interesting facts indicated by the data is the very high efficiency for odor removal. It was expected that good odor removal would be obtained when the tests were planned, but no one was optimistic enough to predict 90 to 95 per cent removal. Slurry recirculation, prolonged contact between the floc particles and the liquor, and high slurry concentrations are undoubtedly prerequisites for such removals.

Not only are the results obtained by Accelator operation on such wastes excellent, but there is the additional advantage in reduced installed cost afforded by this type of unit as compared to a conventional unit.

Kominek (2) has reported pilot plant studies at a large eastern refinery, in which a conventional plant with mixing, flocculating, and sedimentation basins was operated in parallel with an Accelator. A comparison was made of the operating results using alum as the coagulant and also alum with activated silica as a coagulant aid. Figure 5 indicates the comparative oil, solids, and B.O.D. reductions *versus* rise rate. It should be noted that activated silica and alum increased the permissible rise rate in either the Accelator or the conventional plant. At a rise rate of 0.2 g.p.m. per square foot, about 86 per cent oil removal was obtained in the conventional plant when alum was used, and about 95 per cent when alum and activated silica were used. In the Accelator, 90 per cent oil removal was obtained when alum was the coagulant at a rise rate of 0.4 g.p.m. per square foot, and 95 per cent oil removal at a rise rate of 0.8 g.p.m. per square foot

TABLE IV.—Results of Accelerator Pilot Plant Operation on Oil Refinery Waste (Oct. 10 to Nov. 9, 1950)

Test No.	Dosages (p.p.m.)				Av. Red. in Contamination Char. (%)						Remarks
	Alum	Act. Silica	Alk. Agent	Water Soft. Sludge	Odor No.	Oil Cont.	B.O.D.	O_2 Cons.	Turb.	Susp. Sol.	
1[1]	350	20	0 to 550[2]	100	82	83	70	60	95	62	Floc. at pH 8 to 11 satisfactory.
2[3]	350	20	170 to 500[4]	0 to 175	75	84	73	58	95	74	Lime best pH control chem.; softener sludge unnecessary.
3[5]	350	{10 {20	155} 310}	0	73	91	72	74	95	88	Lower dosages satisfactory.

[1] To determine effect of varying pH between 8 and 11.
[2] Caustic.
[3] To determine suitability of alkaline agents.
[4] Dolomitic lime.
[5] To determine satisfactory chemical dosages.

when alum and activated silica were used. In general, with alum as a coagulant, approximately the same percentage reductions were obtained in a conventional plant operated at a rise rate of 0.1 g.p.m. per square foot as in the Accelator operated at 0.4 g.p.m. per square foot. When alum and activated silica were used, approximately equal results were obtained in the conventional plant operated at 0.2 g.p.m. per square foot as in the Accelator operated at 0.8 g.p.m. per square foot. With high construction costs it is difficult to overlook factors which will allow such an appreciable increase in the operating rise rate and, therefore, materially reduce the basin requirements.

Soluble oil wastes from machining operations will, in general, involve higher oil concentrations than those encountered in the effluent of A.P.I. separators in refineries. As an indication, the oil content of the wastes introduced to the treatment plant at the New Departure Division of General Motors at Sandusky, Ohio, has varied between 1,000 and 110,000 p.p.m., according to Unwin(3). These high oil contents are particularly apt to occur when the plant is equipped with a central coolant system, portions of which must be dumped in emergencies or as required for maintenance. The authors have not encountered, as yet, in soluble oil waste treatment, a case where the original estimate of maximum oil concentration has not been exceeded. For this reason it appears only logical to approach these problems, in the majority of cases, by two-stage treatment. The first stage consists of thorough mixing of the waste with a suitable electrolyte (such as ferric sulfate) in a rapid mixing unit, followed by gravity separation and skimming of the oil broken from emulsion in a conventional clarifier. Reduction of the pH to an average of 5.0 to 6.0 in the primary unit will frequently be sufficient to break the emulsions. The break is not entirely clean, however, and subsequent precipitation of the hydroxide of the coagulant in a "high-rate" unit by the addition of lime is required so that essentially all of the remaining oil will be adsorbed on the floc particles.

Removal in the primary clarifier of all but 200 to 300 p.p.m. of the oil appreciably reduces the work that must be done by the final unit. The control of the final unit is therefore greatly

TABLE V.—Results of Accelerator Pilot Plant Operation on Oil Refinery Waste (Jan. 17 to Apr. 3, 1951)

Test No.	Dosages (p.p.m.)				Av. Red. in Contamination Char. (%)						Remarks
	$FeSO_4$	Act. Sil.	Alk. Agent	Water Soft. Sludge	Odor No.	Oil Cont.	B.O.D.	O_2 Cons.	Turb.	Susp. Sol.	
1[1]	8	10	493[2]	0	96	97	63	72	86	76	Results excellent.
2[3]	8	5	455[2]	0	95	99	63	65	88	79	Results excellent.
3[4]	4	2	405[2]	0	90	96	54	56	82	73	Results good.
4[5]	4	2	495[6]	0	93	96	38	57	82	73	Either lime satisfactory.
5[7]	25	5	415[6]	100	96	99	58	66	87	65	Results excellent; less scum formed.

[1] To determine suitability of ferrous sulfate as coagulant.
[2] Dolomitic lime.
[3] To determine effect of reduced activated silica dosage.
[4] To determine effect of reduced $FeSO_4$ and silica dosage.
[5] Evaluation of high-calcium lime.
[6] High-calcium lime.
[7] To determine value of water softener sludge.

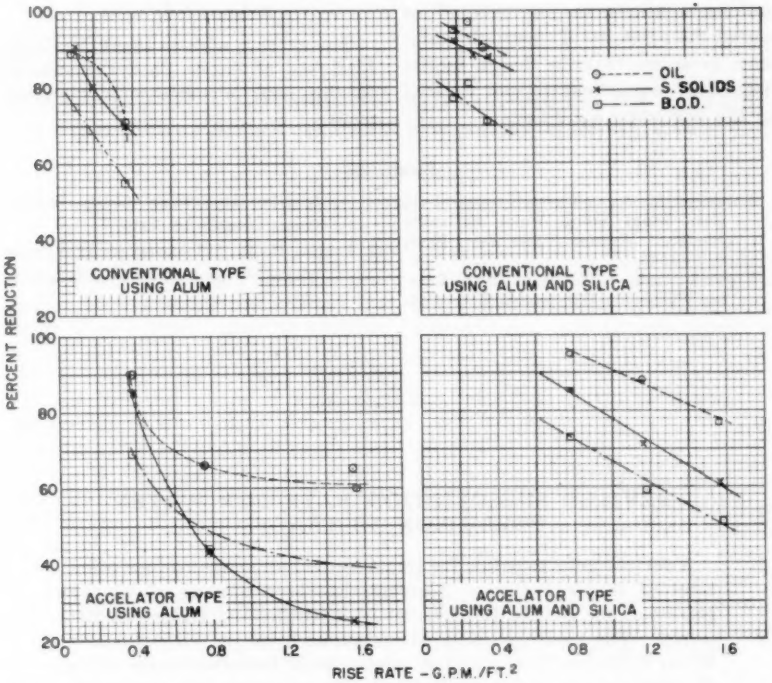

FIGURE 5.—Results of pilot plant studies with conventional and Accelator type units in parallel using alum and alum and activated silica as coagulants.

simplified, increasing the assurance that a highly satisfactory effluent will result at all times, when the variations in the raw waste oil content are ironed out by a first stage. A relatively small amount of electrolyte is required to break the emulsion satisfactorily for gravity separation in the first stage, whereas considerably more coagulant would be required to maintain the proper oil-solids ratio in a single-stage installation. A two-stage plant as described above can produce an effluent containing, on the average, less than 15 p.p.m. of oil. Under proper control such an effluent can be maintained, regardless of fluctuations in the oil content of the raw waste, whereas a single-stage operation would produce this high quality of effluent only under very critical control, if at all. Perhaps it is surprising, but the two-stage plant is not appreciably higher in cost as compared to a single unit, as a higher rise rate can be tolerated in the final unit.

Summary

This paper has touched only briefly on the application of flocculation and clarification equipment in industrial waste treatment. Among other problems presently being resolved by this type of treatment are plating wastes, pickle acid rinse waters, waters containing flue dust, oil field brines, etc. There is little question but that flocculation and clarification equipment has a place in a large number of waste

problem solutions, keeping in mind, of course, the necessity of thorough evaluation to assure that the design limitations of the equipment are not violated by the particular conditions.

Acknowledgment

The authors wish to thank Mr. John Litchfield of Searle Food Corporation for his data on cannery waste treatment.

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REVISED SUBSCRIPTION RATE FOR WATER POLLUTION ABSTRACTS

A revised price schedule for single copies and annual subscription rates of *Water Pollution Abstracts* has been announced by the publisher, the British Department of Scientific and Industrial Research. The monthly publication, prepared by the Department's Water Pollution Research Staff, covers world literature in the fields of water supply, water analysis, sewage collection and treatment, industrial waste treatment, and pollution of natural waters. Author and subject indexes are published annually as a separate issue.

Water Pollution Abstracts is obtainable in the United Kingdom through the various offices of H. M. Stationery Office; in the United States, from the British Information Services, 30 Rockefeller Plaza, New York 20, N. Y. Single copies are priced at 3 *s.* 2 *d.* ($0.80); the annual subscription rate is 38 *s.* 0 *d.* ($8.75).

TREATMENT OF BOARD MILL WASTE AT RIVER RAISIN PAPER COMPANY, MONROE, MICH. *

By M. F. Knack

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The River Raisin Paper Company operates three paperboard machines producing approximately 350 tons per day at its Monroe, Mich., plant, in addition to a strawboard machine producing approximately 55 tons per day. Methods for reducing the volume of waste and for treating this volume have been under study for a number of years and it is with the result of these studies that this report concerns itself. After investigation of various methods of the re-use of white water in the mills it was decided to proceed with a complete system, including a sedimentation unit of sufficient capacity to handle the wastes from two of the paperboard machines. The machines chosen were the two largest from the standpoint of both tonnage and width. The procedure followed in effecting this program was: (1) elimination of all roof water and clear waste water from the mill sewers; (2) arrangement to re-use machine water wherever practical; and (3) provision for ultimate disposal of the mill wastes in a sedimentation unit of suitable capacity and design.

The elimination of all roof water and clear wastes in the case of this mill involved a considerable amount of work and expense. A study of the problem disclosed that about one-third of the roof surface of the rather large buildings housing the board machines and box shops emptied into the mill sewers. It was also necessary to provide a diverting sewer to separate the boiler room wastes from the mill wastes. After this was done the board machine wastes were all collected by the existing mill sewer system to a central sump, where they could be pumped to the ultimate disposal unit.

Re-Use of White Water

It was demonstrated to the satisfaction of the mill operating personnel that it is practical, by the use of suitable shower pipes, to keep the forming molds on a cylinder board machine clean with white water. The water is collected in a flume system under the machine and discharged into a sump, from which it is pumped directly back to the cylinder mold shower pipes. The shower pipes selected were of the fan spray nozzle type with a special cleaning device and were furnished by the Emerson Mfg. Co. The nozzles are spaced 3¼ in. apart and are of 0.156-in. diameter. A pump was provided that would produce 55-lb. pressure at the shower pipe inlet. A second set of pumps was provided to pump the white water through a high-velocity heater for use in the beaters and pulpers, which prepare the fiber furnish for the paper machines. The heater used to heat this water was selected with easy cleaning in mind. The tubes are straight and doors on both ends can be opened so that the tubes can be cleaned by shooting through rubber plugs with air pressure.

Fresh water is used on the board machines wherever clear water is required (such as for washing felts, for foam showers, and in pump glands). The largest volume of fresh water used on

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the machine is used in washing the felts. The shower pipes used on the felts are also fan spray nozzle types with the nozzles spaced 3½ in. apart. The nozzles on these showers are of 0.125-in. diameter and the shower head pressure is 65 lb. per sq. in. Two showers are provided for both the top and bottom felts. In addition, there are two wetting showers on the felts with 0.093-in. nozzles spaced 4 in. apart. These showers are not operated at full pressure, but are turned on just enough to keep the felt wet ahead of the felt rolls. The felt shower water on each machine totals approximately 650 g.p.m. and this water is allowed to run into the collecting sump under the machine to provide sufficient fresh-water make-up for the system, so that heavy momentary demands do not empty the machine sumps.

Clarifier System

The unit chosen for clarification of the final mill effluent is an Infilco Cyclator with a rated capacity of 2,100 g.p.m. This unit allows approximately 100-min. retention at full capacity. Alum and activated silicate are the coagulants used. A measuring weir on the discharge from the unit regulates the chemical feed in proportion to the flow. The chemicals are added in the center section of the unit, where the waste water is introduced. This center section is so arranged that the waste water is recirculated in concentric tanks after the coagulants are added to aid flocculation. The rate of recirculation may be varied. After the mixing treatment the waste enters the quiescent zone in the tank, where settling takes place. The settled sludge is drawn by rakes to a concentrating well at the center of the tank, from which it is drawn off by a time-operated diaphragm valve and returned to the mill for re-use. The clarified effluent is discharged to the stream.

Operating Efficiency

Before installation of this system these two board machines, operating in pretty much an open system, discharged approximately 5,000 g.p.m. to the stream carrying an average of about 3.0 lb. per 1,000 gal. of suspended solids. At present the discharge from the Cyclator unit averages 1,600 g.p.m. Table I shows the suspended solids and B.O.D. removal in the unit, as based on an average of three tests conducted in 1948 by the Michigan Stream Control Commission.

Table I indicates a reduction in 5-day B.O.D. in the Cyclator unit of approximately 58 per cent. The suspended solids reduction is about 92 per cent. It should be noted that the suspended solids in the effluent from the settling unit are only 5 p.p.m. greater than the mill raw-water supply. The volatile solids, which are about 70 per cent of the total, are assumed to be fibrous and represent the valuable portion of the sludge.

TABLE I.—Operating Data for White Water Treatment Unit

	Raw Plant Process Water	Treatment Influent	Plant Effluent	Sludge to Process
5-day B.O.D. (p.p.m.)	3.5	139	58	—
Susp. solids (p.p.m.)	39.	593	44	17,650
Susp. vol. sol. (p.p.m.)	11.	396	24	11,450
pH	7.7	6.8	6.6	6.4
Pumping rate (m.g.d.)	2.36	—	—	—
Population equiv.	5,807	—	—	—
Fresh water used (gal./ton)	15,000	—	—	—
Production (tons/day)	156	—	—	—

Operating Experience

Original tests on the wastes from these board machines indicated that a treatment with 6 to 8 grains of alum and 10 p.p.m. of activated silicate would give satisfactory clarification. The samples on which these conclusions were based were taken before complete closing up of the mill system by recirculating the water. Actual operating experience has indicated that an average alum requirement is from 10 to 12 grains per gallon. The alum requirement is, of course, influenced by the waste paper furnish used in the mill. At times chemical bags containing all varieties of chemicals are used; after recirculation, a buffered waste develops that takes heavy alum treatment to coagulate. The use of activated silicate seems to produce clearer, quicker settling wastes and experience seems to indicate that the difference is much more pronounced during winter operation than in the summer. Winter operating temperature in the Cyclator is about 70° F., whereas summer operating temperature is about 105°F.

Problems from Re-Use of Sludge

As indicated by the surveys made by the Michigan Stream Control Commission, the sludge from the Cyclator is approximately 70 per cent volatile. This volatile matter is assumed to be, for the most part, fiber. The balance is dirt and precipitated chemical or insoluble filler. The sludge is returned continuously to the papermaking process. Experience to date has not proven that the return of this material is detrimental. An attempt is made to divide the sludge between two waste paper pulping units that handle an excess of 150 tons per day and it is felt that the relatively small tonnage of sludge will not usually have adverse effects on the paper machines.

No provision was made for withdrawing sludge from the unit when the paper machines were not operating. Experience has shown that the sludge may be held in the clarification tank during normal shutdown periods and drawn off in the normal manner after the machines have been started. During a 3-day shutdown period over a week-end, the sludge retained in the tank became septic. By the end of the third day the entire tank was black and gassy. Operation was resumed without draining and cleaning the tank and within 4 hr. clear effluent was obtained. The tank did not become septic on the next week-end shutdown. It was necessary to drain and clean the tank four weeks later because of a septic condition, but it was felt by the operators that this was caused by faulty sludge removal. The sludge ports were partially clogged by sticks and rags and proper removal of sludge had been difficult for more than a week. Experience seems to indicate that under normal operating conditions it is necessary to drain and clean the tank not more than twice a year.

Economics

It is rather difficult to analyze the economics of this sort of installation because the value of the recovered fiber is debatable. The volatile portion of the sludge probably should be evaluated at the price of the cheapest raw material used in the process which, in the case of this mill, is mixed waste paper. The problem is further complicated by the fluctuation in the price of these raw materials and the relatively stable cost of the chemicals used for treatment. The following is a rough cost tabulation:

Alum (11 gr. av. feed based on 1,600-g.p.m. av. flow)	$ 67.50
Activated silicate, 10 p.p.m.	8.35
Power for pumps, at $90/hp./yr.	18.00
Labor and maintenance	20.15
Interest on investment	8.35
Total cost	$122.35
Recovery (11,000 lb./day @ $20/ton)	$110.00

The above analysis does not indicate that the clarification unit is self-sup-

porting, but the over-all picture, which includes the saving made by recirculation of white water in the mill, is more encouraging and probably will show that the whole project is at least self-supporting.

Conclusion

On the basis of experience in this mill it has been demonstrated that the re-use of white water to reduce the total volume of mill effluent is practical. A high-rate sedimentation unit has been adapted to the treatment of the final mill effluent and seems to be giving very satisfactory results. The economics of the system do not present such an attractive picture if the final sedimentation unit is made to stand alone, but are not too discouraging if the economies effected by recirculation of water in the mill are considered.

SMOKE ABATEMENT BOOKLET

Under the title "Application of Overfire Jets to Prevent Smoke from Stationary Plants," Bituminous Coal Research, Inc., has published the first of a new series of coal research publications to be known as "BCR Aids to Industry." The present booklet carries the identification number 500–300 and is a revision of "Technical Report 7," which has become a standard for the design, construction, and application of overfire jets to abate smoke from stationary plants.

The engineering information in the current revision is substantially the same as that of "Technical Report 7," rearranged to make the information as easily used as possible. Design data and sample calculations, together with illustrative diagrams, are given for blower jets, steam-air jets, and plain steam jets. Also included is a short but information-packed section on control and care of jets and a design summary for each of the various types discussed.

The booklet is available from Bituminous Coal Research, Inc., 2609 First National Bank Building, Pittsburgh 22, Pa., at $0.50 per copy.

ACTIVATED SLUDGE TREATMENT OF MILK WASTES *

By Paul M. Thayer

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This paper is in the nature of an interim report on the general subject of treating milk waste by the activated sludge process. It has only been in the last few years that this method has generally been accepted as being feasible. However, experience with this method of treating milk waste goes back a good many years.

An activated sludge plant was built in 1935 to treat the waste from the dairy at New Bremen, Ohio. In 1939 a report on the operation of this plant, made to the 13th Ohio Conference on Sewage Treatment by E. F. Hatch and J. H. Bass of the Ohio State Board of Health, disclosed that the B.O.D. removal was 98.9 per cent. The plant has been in successful operation ever since.

About 1945 the plant for treating the waste from the Belle Center Creamery at Belle Center, Ohio, was changed from an experimental high-rate filter plant to an activated sludge plant. Operating data and experience records from this plant have been presented to this association on at least two occasions. This plant consistently reduces the B.O.D. from 97 to 99 per cent.

In 1950 two new activated sludge plants treating milk waste were put into operation. The first one was at the Schell Creamery near Germantown, Ohio, and the other at the Blossom Hill Dairy, Dayton, Ohio. Both of these plants have given a B.O.D. reduction of around 97 to 98 per cent. Another activated sludge plant was recently placed in operation at the Cherry Grove Dairy in Toledo, Ohio.

New Bremen Plant

The New Bremen plant was of the conventional type, with a mixing tank for feeding lime slurry (detention time, 2 hr.), a primary settling tank (detention time, 4 hr.), an aeration tank (detention time, 41 hr.), and a final settling tank having a detention time of 4 hr. The total blower capacity was 263 c.f.m. Excess sludge is withdrawn from the final settling tank to a disposal field occasionally, but, in the main, the settled activated sludge is all returned to the aeration tank.

Belle Center Plant

The Belle Center Creamery plant consists of an aerated sump of 12,500-gal. capacity; two aeration tanks totalling 23,760-gal. capacity; two clarifiers totalling 23,950-gal. capacity; a digester of 11,450-gal. capacity; and three blowers with a total capacity of 750 c.f.m. The average daily flow of milk waste, as given by Eldridge (1), was 30,353 g.p.d., and the B.O.D. reduction from a raw of 936 p.p.m. to a final effluent of 11 p.p.m.

In the operation of this plant the raw waste flows to the aerated sump; from the sump it is pumped through controlling orifices to the two aeration tanks, the excess pumpage being spilled back to the sump. Excess sludge is wasted to a sludge concentration tank, the concentrated sludge going to the digester and the lighter sludge going back to the sump; supernatant from

* Presented at 25th Annual Meeting, Ohio Sewage and Industrial Wastes Treatment Conference; Columbus, Ohio; June 20–22, 1951.

the digester also flows to the sump. During the first few years of operation no sludge has been drawn from the digester. Activated sludge from the two clarifiers is returned to the aerators at a rate of 600 to 700 per cent of the raw sewage flow.

Schell Dairy Plant

The plant at the Schell Dairy consists of two aeration tanks in series having a capacity of 6,200 gal., and one settling tank having a capacity of 450 gal. The single blower has a capacity of 85 c.f.m. Provision is made to restrict the flow from the aeration tank to the settling tank so as to reduce the surge of fluctuating flow through the settling tank. All sludge is returned to the influent end of the aeration tank by means of an air lift. The average daily rate of raw sewage flow is 4,400 gal. and the rate of return activated sludge is from 500 to 700 per cent of this figure.

Blossom Hill Dairy Plant

The Blossom Hill plant consists of an aerated holding tank having a capacity of 3,420 gal.; two aeration tanks in series having a capacity of 12,300 gal.; a final settling tank having a capacity of 970 gal.; and a 100-c.f.m. blower. All sewage flows into the aerated holding tank (Figure 1) and is pumped from there through a division box, which discharges over a 90° V-notch weir to the aeration tank on one side and over a long rectangular weir back to the aerated holding tank on the other. This arrangement makes it possible to get a practically constant rate of flow through the aeration and final tanks, regardless of the widely fluctuating flow coming into the aerated holding tank. All sludge is returned from the settling tank to the influent end of the aeration tank.

Flow through the plant is about 8,000 g.p.d.; the rate of sludge return is 400 to 500 per cent.

Cherry Grove Dairy Plant

The Cherry Grove Dairy plant consists of an aerated holding tank having a capacity of 8,200 gal.; an aeration tank having a capacity of 15,200 gal.; a final settling tank having a capacity of 4,000 gal.; and a 100-c.f.m. blower. The raw sewage flows into a division box, which discharges over a 90° V-notch weir to the aeration tank, and over a rectangular weir back to the aerated holding tank. A pump lifts the waste from the holding tank to the influent end of the division box. This arrangement provides means for maintaining a nearly constant rate of flow through the aeration and settling tank, regardless of the fluctuating rate of

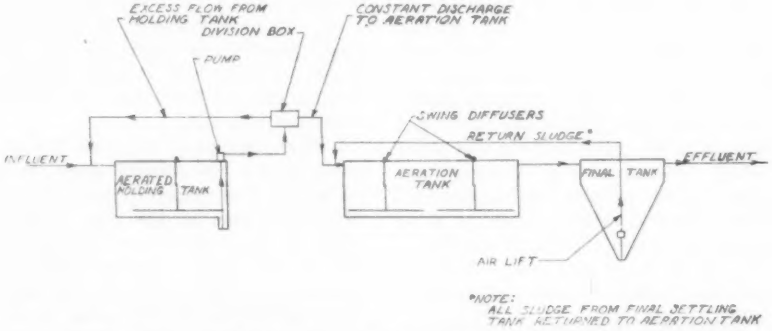

FIGURE 1.—Schematic flow diagram of milk waste treatment plant employing the activated sludge process.

waste discharge from the dairy. An air lift returns all the sludge from the settling tank to the influent end of the aeration tank.

Simple to Operate

The operation of the last three plants mentioned is very simple. There is only one valve that can be adjusted—the ¾-in. valve controlling the air supply to the air lift. The 90° V-notch weir is set so that the total flow over it in 24 hr. is equal to the total flow coming to the plant in 24 hr., even though this total flow comes in a period of 5 to 7 hr. The rate of return of the settled sludge is not critical; best operation seems to be achieved when this rate is from 400 to 700 per cent of the average daily flow through the plant, and has no relationship to the momentary rate of flow through the plant.

Experience with the plants mentioned indicates clearly that treatment of dairy waste by the activated sludge process is entirely practical, that such plants can be made extremely simple, and that the operation of them can be reduced to seeing that the blower and pump are kept operating and the diffuser media are kept clean. The advantage of having an aerated holding tank to equalize the flow through the aeration and settling tank and to composite the wastes from the dairy is very marked. The idea of disposing of all milk solids by means of aerobic action has been proven practical.

There now remains the problem of working out the most economical designs for this type of plant. That can best be done by making a continuing study of plants of this type treating milk waste, correcting errors in existing plants as they develop, and improving equipment to meet actual operating problems as they arise.

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CANNERY WASTE TREATMENT AND DISPOSAL *

By C. W. Templeton

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Waste treatment and disposal for large or small seasonal canneries has been an increasing problem since the day that discharge direct to open streams became unpopular. The short periods of operation make the cost of adequate treatment facilities considerably greater in proportion to plant production than in a year round operation. Therefore, the seasonal cannery has had to develop its own methods of waste treatment, which are often adaptations of other industrial treatment methods, but with many improvisations of their own.

Three common methods of waste treatment are discussed herein, as well as one new method which was studied during the 1950 season. The methods or systems are:

1. Discharge to municipal treatment plants.
2. Lagooning, with added chemical stabilization.
3. Soil absorption.
4. Anaerobic digestion, first attempted in this field during 1950.

Municipal Treatment

The most desirable solution to the waste disposal problem for both the canner and the community is treatment by the municipal sewage treatment plant. Unfortunately, the seasonal canning plant is most often located in rural areas where adequate municipal facilities are not available. In fact, the municipal plants of most villages and towns are overloaded by the communities' sanitary sewage, and for financial reasons can not contemplate extending facilities to handle cannery waste. The seasonal canning plant waste load often exceeds the sanitary load of the entire community. The cannery peak also comes at the season of the year when stream flow is low, so the treatment plant must be operated at peak effectiveness, whether or not it has the additional cannery waste.

Perhaps credit should be given here to the town of Norwalk, Ohio, one of the few towns near which Stokely operates a seasonal plant that is fortunate in having a treatment plant capable of handling its sanitary load and the canning plant waste. Such an arrangement is advantageous to the canner and to the welfare of the community. Also, in all probability, the extra assessment is a welcome addition to the municipal plant budget.

Lagooning

The method of waste treatment most widely used by the company is lagooning. Lagooning consists merely of a suitable basin to impound the entire season's production of screened liquid waste. The waste is held long enough to permit stabilization and is then released into a watercourse. Sodium nitrate usually is added to accelerate stabilization and minimize odor production. Experience has shown that the addition of nitrate in amounts of 150 lb. per 1,000 cases of peas and 200 lb. per 1,000 cases of corn or tomatoes will normally keep odor production under control and will complete stabilization in a suitable period of time.

* Presented at 25th Annual Meeting, Ohio Sewage and Industrial Wastes Treatment Conference; Columbus, Ohio; June 20–22, 1951.

The plant waste is screened through a 10- or 20-mesh vibrating screen before introduction to the lagoon. Screens of 40 and even 60 mesh are often recommended, but personal experience indicates that they are less effective than the larger screens, due to blinding of the screens, with consequent overflow of solids into the pump sump.

Sodium nitrate is usually added in the pump sump. It may be added dry or in solution. The author prefers putting the nitrate in solution and letting the required amount drip into the sump over the entire operating day. The important feature of nitrate application is not the method of introduction, but to be certain that the required amount is added each day. If insufficient nitrate is added at the start of the pack, the addition of overdoses later on will be relatively ineffective. At Stokely, the "eye and nose" test is used to determine whether the addition of nitrate is satisfactory. If the odor is offensive and the water has a grayish appearance, more nitrate is indicated. If the odor is no more effensive than that of a well-kept stable, and the water has a green to brown appearance, with small amount of brown scum, the application of nitrate is considered sufficient.

The depth of the lagoon should not exceed 4 ft. This permits sunlight penetration to the bottom, which accelerates the stabilization process.

Good housekeeping includes keeping weeds around the edge of the lagoon closely cropped to control mosquito breeding. Also, 1 pt. per day of a concentrated emulsion carrying in excess of 25 per cent DDT is introduced into the pump sump. It effectively controls the production of mosquito larvae.

Lagoons require frequent inspection, as burrowing rodents often do extensive damage to the banks.

Stokely's experience with lagoons has been generally satisfactory, but occasional production of odor is still encountered. This system of waste disposal does require proper attention in all phases of operation. Once a lagoon gets out of control, it is practically impossible to regain control for the rest of the season.

Soil Absorption

The soil absorption method of waste treatment and disposal, as practiced by the Stokely organization, varies only slightly from the lagoon method. The principal difference is that the waste is never drained from the lagoon, but is absorbed into the soil. Prior to the next season's pack the lagoon is plowed. The choice between the two methods depends primarily upon local soil conditions.

Anaerobic Digestion

Sodium nitrate is an expensive item in lagoon treatment, so for some time ways and means to eliminate its use have been considered. In this direction the Stokely company cooperated, during the 1950 season, with the National Canners Association and Professor Don E. Bloodgood, of Purdue University, in studies of anaerobic digestion. Full-scale test operations were conducted at the company's Greenwood, Ind., and Beaver Dam, Wis., plants. The Beaver Dam operation and study is fully reported in Research Report No. 1–51 of the Washington Research Laboratories of the National Canners Association. The report was written by N. H. Sanborn and R. A. Canham. Due credit is given to this report, from which the following data and observations on anaerobic digestion have been taken.

The theory of anaerobic digestion is to hold the raw liquid waste in intimate contact with suspended solids which have the ability to accelerate decomposition. Usually this type of digestion is carried on at elevated temperatures in inclosed digestion units, but for reasons of economy this study was conducted in an open pond without temperature control.

The digester unit was an open pond, 80 ft. wide, 270 ft. long, and 7 ft.

deep, with a capacity of 1,000,000 gal. One wall of the digester was common to the storage lagoon, which had a capacity of 7,000,000 gal. The digester was seeded with 175,000 gal. of digested sludge supplied by the Beaver Dam municipal sewage treatment plant. The first or anaerobic stage of reduction was accomplished by agitation supplied by four heavy-duty "Lightnin" mixers individually mounted on rafts so their position could be varied for experimental purposes. From the digester the waste overflowed into the storage lagoon, where the second stage of reduction occurred without further treatment except that occurring naturally in a storage lagoon.

Pea Pack

During the pea pack, the raw waste flow varied from 75,200 to 405,000 g.p.d. Such fluctuations are to be expected in the canning of seasonal products, but they render difficult the interpretation of certain data relative to the performance of the treatment plant. The B.O.D. of the raw waste on canning days varied from 245 to 1,690 p.p.m., with an average of 790 p.p.m.; the digester effluent varied from 351 to 859 p.p.m., with an average of 564 p.p.m. The B.O.D. of the storage lagoon ranged from 46 to 346 p.p.m., averaging 183 p.p.m. The B.O.D. loading, in terms of pounds per 1,000 cu. ft. of digester capacity, for canning days varied from 1.2 to 31.7, with an average of 18.2. The detention time in the digester on canning days varied from 2.34 to 12.6 days, with an average of 3.56 days.

The pH of the raw waste varied from 7.2 to 8.0, with an average of 7.5; the digester effluent pH varied from a lower value of 6.0 to 7.0 to something above 8.4 (the limit of the available colorimetric pH kit), averaging approximately 8.0.

The raw waste temperature varied from 72° to 90° F., with an average of 80.5° F. The digester effluent temperature ranged from 72° to 84° F., averaging 77° F.

The average B.O.D. reduction, based on the quantity of B.O.D. entering the digester and that leaving the digester, was 37.8 per cent, equivalent to 870 lb. per day, or 6.85 lb. per 1,000 cu. ft. of digester per day. Under the conditions actually prevailing, the B.O.D. reduction through the storage lagoon, to the end of pea pack only, was approximately 58 per cent; through the combined digester and lagoon the reduction was 74 per cent.

As a matter of interest, but not presented as data suitable for the calculation of B.O.D. reductions, the B.O.D. at the end of the pea pack was 320 p.p.m., whereas one month later it was only 20 p.p.m. The average B.O.D. of the raw pea waste was 790 p.p.m.

A few days after operations began, the digester developed a hydrogen sulfide odor. Twelve days after the start this odor could be detected up to 800 ft. from the digester. It was believed that loss of sludge through the overflow opening was responsible for the gradual increase in odor, so sludge was added. Within a few days after the addition of sludge, a diminution of odor was apparent. It is believed that odor production would not be objectionable if sufficient digester solids were present. Hydrogen sulfide was the only odor produced in the digester.

The storage lagoon did not develop an odor intensity considered objectionable. On several occasions a little hydrogen sulfide odor was noted near the point where the digester waste entered. The predominant odor of the storage lagoon was an ammoniacal or amine odor, suggestive of cow urine, and was recorded as "urine." Usually the odor was not noticeable, even when standing on the banks of the lagoon.

The digester remained black in color during the entire pea pack. The storage lagoon developed a green color at the start of the pack, but became progressively darker. After heavy rains

the lagoon became light green in color, only to darken again as the season progressed. The darkening in color may have been due primarily to black sludge carried over from the digester.

Corn Pack

The digestion system was operated in the same manner for the corn pack as it was for peas, except that a settling chamber was added at the digester overflow to diminish the overflow of sludge. During the corn pack the raw screened waste varied from 32,500 to 150,000 g.p.d. The detention period in the digester ranged from 6.35 to 29.2 days, with an average of 11.3 days.

The 5-day B.O.D. of the raw waste varied from 1,187 to 3,051 p.p.m., with an average of 2,169 p.p.m.; the digester effluent B.O.D. varied from 165 to 1,622 p.p.m., with an average of 1,068 p.p.m. The lagoon B.O.D. ranged from 20 to 201 p.p.m., averaging 185 p.p.m.

On the basis of the total quantity of B.O.D. fed to the digester and that which overflowed, the average B.O.D. reduction was 56 per cent, equivalent to 930 lb. per day or 7.33 lb. per 1,000 cu. ft. of digester per day. This does not take into consideration the amount of B.O.D. retained in the digester.

Considering separately the pounds of B.O.D. entering the lagoon, a reduction of 75 per cent was effected by the lagoon during the period covering the corn pack only. On an over-all basis, the B.O.D. reduction through the digester and the lagoon was 89 per cent. No doubt considerably greater reduction would have been found had data been obtained for periods beyond the corn pack.

A few days after the corn pack started a slight hydrogen sulfide odor was noted at the digester. This odor increased in intensity only slightly and leveled off for the balance of the season. At no time was the odor of such intensity that it could be detected at a distance of more than 50 ft. The lagoon developed a very slight urine odor, but this was never noticeable beyond the lagoon banks.

The color of the digester became influenced by the starch in the corn and remained a dark gray throughout the pack. The lagoon maintained a greenish color during the entire season, gradually increasing in intensity.

General Observations

The study of a new treatment process operating for only a few weeks under radically changing conditions makes generalized conclusions difficult, if not impossible. If the conditions that prevailed during the corn pack could be considered as normal, it could properly be concluded that, so far as abating stream pollution is concerned, treatment was satisfactorily accomplished without objectionable odor formation. It is presumed that had there been no loss of solids from the digester during the pea pack, less odor would have been produced. A further study of anaerobic digestion at Beaver Dam will be undertaken during the 1951 season.

The cost of treatment amounted to $6.18 per 1,000 cases of No. 2 cans packed, calculated on the basis of the power consumed by the mixers, amortization of the cost of the mixers over a 5-year period, and amortization of the digester and lagoon over a 10-year period. If the construction and installation costs are amortized over a 20-year period, the cost of treatment would amount to $4.75 per 1,000 cases of No. 2 cans packed. It is interesting to note that had sodium nitrate been used at the 1949 dosage rate the cost of nitrate alone would have been $7.79 per 1,000 cases of No. 2. cans.

Considerable confidence is placed in the future of anaerobic digestion systems, but a decision has not yet been reached to adopt it for regular operations.

Chemical Precipitation

Perhaps mention should be made of chemical precipitation which was very popular in Wisconsin until recent years. The Health Department of that state now recognizes these systems as being less than 50 per cent effective for canning plant waste treatment. Stokely has two such systems at Astico, Wis.; one for a pea plant, the other for a corn plant. As the pea and corn seasons do not overlap, both treating plants are used for each pack. This gives increased precipitator capacity for each pack, and extends the operating period of each treatment system, which is considered beneficial; yet this system is not considered to be more than 50 per cent effective.

Poly-Cide

Several commercial materials have recently appeared on the market with claims ranging from odor control to B.O.D. reduction ability. One of these, called Poly-Cide (sold by Brooks Boiler Treatment Company), was tried. The study of this material has been limited to a small number of plants during one season; therefore, the following is offered merely as observations and is not to be taken as considered recommendation or condemnation of such materials.

Poly-Cide is considered to be an odor-masking agent, as it is very odoriferous itself. Experience during the study does not indicate that it materially contributes to B.O.D. reduction or that it can be considered a replacement for sodium nitrate. At Gibson City, Ill., it was found effective for odor control in a soil absorption lagoon. At Paulding, Ohio, in a straight lagoon system, it was effective during the season, but lost odor control immediately after the pack was completed. Considerable difficulty was encountered when the lagoon was drained.

Poly-Cide was found very effective for odor control when sprayed around the base of pea vine stacks and around the stack waste drainage canals. At Gibson City approximately 2 gal. per day were used for this purpose at a cost of $6.50 per day for materials only.

As previously stated, the Poly-Cide did control odor in the soil absorption lagoon at Gibson City. The flow of liquid corn waste ranged from 275,000 to 500,000 g.p.d. Poly-Cide was regulated to drip into the pump sump at the rate of approximately 22 g.p.d. (16 hr.), which cost $70 per day for material.

Further study of this type of material is expected to be made during the 1951 packing season.

Waste Utilization

Any discussion of canning waste disposal would not be complete without mention of waste utilization. There is considerable nutritive value in most canning plant wastes. When these can be economically reclaimed, not only is the waste disposal problem alleviated, but some expense also is eliminated.

The dehydration of citrus peel is profitably accomplished by several plants in Florida. There is a ready market for the product to cattle feeders.

Pilot plant operations on recovery and dehydration of tomato plant wastes have been reported (1). The dehydration was successfully accomplished and the product was sold for an ingredient of canned dog food. However, the volume of waste available at any one plant was insufficient to justify the cost of a commercial installation.

The waste of apple sauce production has been processed to produce a concentrated flavoring material. This is understood actually to have been developed into a major item in some instances, so that it is the prime product and replaces the apple sauce production from which it was originally a by-product.

The dehydration of pea vine waste into a meal suitable for an ingredient of stock feed has been accom-

plished. Stokely has been interested in these operations, but to date has made no actual study or test operations.

Conclusion

In conclusion, each plant is considered as an individual problem; no one treatment method has been found that is ideal for all seasonal canning plants. However, one or a variation of the systems mentioned can be adapted to almost any plant. Naturally, there are other systems just as practical, but this report has been confined primarily to experience with the Stokely operations.

Reference

1. Templeton, C. W., "Dehydration of Tomato Wastes." Proc. of Third Indus. Waste Conf., Purdue Univ., Extension Series No. 64, p. 258 (1947).

PLANT MAINTENANCE CONFERENCE TO BE HELD IN PHILADELPHIA

In the most extensive discussion of plant maintenance problems ever undertaken, Manly Fleischmann, administrator, Defense Production Administration, will head a group of 56 speakers at the Plant Maintenance Conference, Convention Hall, Philadelphia, Pa., January 14–17, 1952. The exposition management, Clapp & Poliak, Inc., of New York City, expect more than 14,000 to attend, with 225 companies exhibiting.

Special emphasis in both the conference and the exhibits will be placed on preventive maintenance to help industry meet the huge military and civilian production schedules of 1952; but it is from such industrial know-how that the basic advancements in treatment plant maintenance are derived. The conference is sponsored by the American Society of Mechanical Engineers and the Society for the Advancement of Management. The American Society of Lubrication Engineers conducts the panel on lubrication.

The conference will be divided into more than 30 separate sessions to accommodate special talks on individual industry needs and to permit discussion of problems arising in plants of varying sizes and maintenance needs. Particular problems to be discussed include maintenance of plant buildings, electrical equipment, mechanical equipment, power-plant and service equipment, and materials handling equipment. General sessions will be on maintenance costs, project separation, in special methods, scheduling of maintenance work, training of workers and supervisors, personnel, operating policies, safety and plant protection, housekeeping, and welding.

Further information regarding details of the program may be obtained from Clapp & Poliak, Inc., 341 Madison Ave., New York 17, N. Y.

STUDIES OF BIOCHEMICAL OXIDATION BY DIRECT METHODS

II. Effect of Certain Environmental Factors on the Biochemical Oxidation of Wastes *

By H. Heukelekian and I. Gellman

The direct method of oxygen utilization suggested originally by Sierp was improved and modified by Falk and Rudolfs (5). Additional improvements have been made since then by Gellman (6), who also described the use of Warburg apparatus. The Warburg apparatus, as another method for the measurement of B.O.D. of sewage, was used by Caldwell and Langelier (1). Dawson and Jenkins (2)(3) used the Warburg apparatus for determining the oxygen requirements of activated sludge and the effect of addition of chemicals on the oxygen uptake by activated sludge. The use and applications of the direct oxygen utilization method (Sierp) in the study of oxidations of industrial wastes were illustrated by Heukelekian (9).

Since then, extensive studies have been made under a grant from the National Institute of Health on oxidations of sewage and industrial wastes by the use of both the Sierp and Warburg apparatus. These direct methods of oxygen utilization have been used successfully as laboratory tools for studying the factors influencing the oxidation of wastes, similar to the laboratory method used for studying their digestion by the use of gas production as a parameter. The purpose of this paper is to present some of the work done under this project dealing with the effects of environmental factors on the oxidation of sewage and industrial wastes. The factors considered in this paper are:

1. Effect of pH value.
2. Effect of nutrient addition.
3. Effect of substrate concentration.
4. Effect of volume and source of sewage seed.
5. Effect of seed adaptation.

The direct method can be used for the determination of B.O.D. of sewage and industrial wastes, but this is not the primary objective of this paper. However, there are certain advantages in determining the B.O.D. of wastes by the direct method. The rate of oxygen utilization can be determined from a single unit rather than by the great number of dilutions required for the determination of daily rates by the standard dilution or the excess dissolved oxygen method. What cannot be done by the latter methods is the determination of the oxygen demand at any concentration of the waste, because of the limitation imposed by the low solubility of oxygen in water. There are no such limitations in the direct methods and the oxygen demand can be determined at any concentration, either without dilution of even the most concentrated waste, or with dilutions. The limits of oxygen demand that can be determined by these two direct methods have been set forth by Gellman (6). Furthermore, the effect of environmental factors such as are described in this paper would be almost impossible

* Paper of the Journal Series, New Jersey Agricultural Experiment Station, Rutgers University, New Brunswick, N. J.

Part I of this series appeared in This Journal, **23**, 10, 1267 (Oct., 1951).

to determine by the excess dissolved oxygen method. It is for these reasons that in this paper the use of the term B.O.D., as a unit of expression, has been carefully avoided in order to emphasize the difference in concept and approach.

Methods and Procedures

The general methods dealing with the use of the Sierp and Warburg apparatus have been described by Gellman (6), and the specific procedures used for the different phases of the work will be presented in conjunction with the different experiments. The pH values of the wastes were adjusted whenever necessary to 7.0 to 7.2, except in the special studies dealing with the effect of pH on the oxygen utilization. Nutrient requirements were satisfied, in wastes which were deficient, by the addition of salts of nitrogen and phosphorus, except in studies dealing with the determination of the actual quantities of these elements required. Adequate seeding was provided in all cases. The nature and the quantity of seed was varied for special studies dealing with this phase of the problem. All incubations were made at 20° C.

Effect of pH on Rate of Oxidation

To determine the effect of pH values on the oxidation rates, the wastes were adjusted to pH 5, 6, 7, 8, and 9 after supplementation with nitrogen and phosphorus. The samples were seeded with 2 per cent by volume of sewage. The oxygen utilization rate of the adjusted samples was determined in the Sierp apparatus for a period of 5 days. The oxygen utilizations at the different pH values are presented (Figure 1) as percentages of the values obtained at pH 7.0 after 1, 3, and 5 days. In board mill white water the oxidation rate was not affected within a range of pH values from 6 to 8. At pH

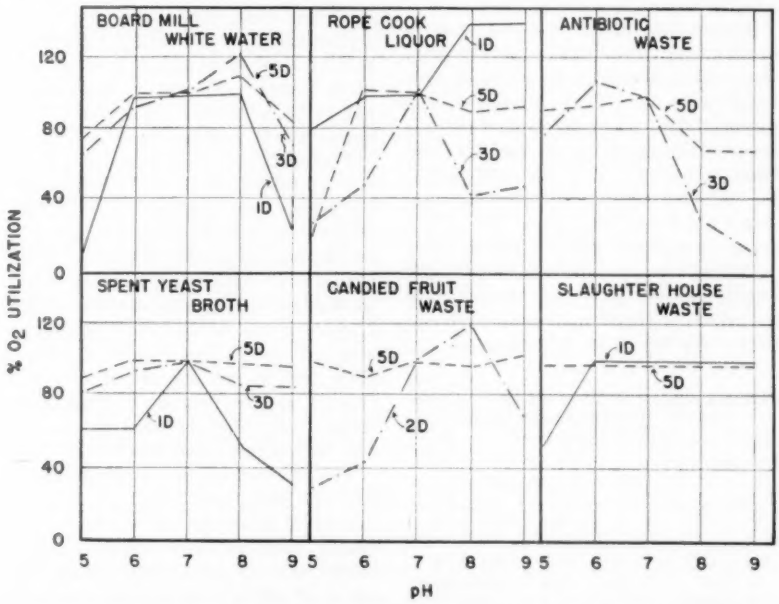

FIGURE 1.—Oxygen utilization of six industrial wastes at pH 5 to 9 expressed as percentage of oxygen demand at pH 7.0.

values of 5 and 9 the oxidation was retarded. The retardation was more pronounced with the shorter periods of incubation. The oxidation of rope cook liquor was not affected within a range of pH values from 6 to 9 after 5 days of incubation. At a pH value of 5 there was a pronounced retardation, even after 5 days. The relative oxidation after 1 day was greater at pH 8 and 9 than at pH 7.0 and there was no pronounced retardation at pH 5.0. In 3 days the oxidation was lower at the acid and alkaline side of pH 7.0. Additional work with this waste, at pH values above 9, indicated that at a pH value of 10 the oxidation was lower than at pH 9, and at pH 11 there was no oxidation during a period of 4 days.

Antibiotic waste seems to oxidize better at the acid side of pH 7.0 than on the alkaline side. The relative rate was not much lower at pH 5.0 than at pH 7.0 after 3 or 5 days, but the relative oxidation at pH 8 and 9 was decidedly lower than at pH 7.0.

Spent yeast broth did not show a pronounced pH preference. The relative oxidation rates were uniform over a pH range from 5 to 9 except during the first day, when the oxidation was lower at either side of pH 7.0. Candied fruit waste also had a wide pH range; the relative oxidation dropped only above pH 8.0 after 5 days, but with a 2-day incubation period the relative oxidation was lower below pH 7.0. There was similarly no difference in the relative oxidation of slaughterhouse waste over the entire pH range of 5 to 9 in 5 days. In 1 day the relative oxidation was lower at pH 5.0 than at higher pH values.

TABLE I.—Effect of Initial pH on the Oxidation[1] of 1:20 Spent Sulfite Liquor Using Adapted Seed

Time (hr.)	Initial pH			
	4	5	6	7
4	25	155	330	415
21	335	815	930	1,010
Final pH	4.5	7.3	7.8	7.9

[1] Results expressed as p.p.m. O_2.

TABLE II.—Effect of Initial pH on the Oxidation[1] of 1,000 P.P.M. of Ethyl Acetate

Time (days)	Initial pH						
	4	5	6	7	8	9	10
1	0	0	35	60	85	15	0
2	0	35	155	305	490	25	5
3	15	185	370	490	640	405	55
4	20	245	425	805	810	750	245
Final pH	3.6	3.1	3.2	3.3	3.3	7.6	7.7

[1] Results expressed as p.p.m. O_2.

In general, for the oxidation of most industrial wastes there is a rather broad pH range, which extends from at least 6 to 8, especially with longer incubation periods. The initial lag caused by unfavorable pH values is overcome with longer periods of incubation. Some wastes, such as spent yeast broth, slaughterhouse waste, and rope cook liquor, oxidized as readily at pH 9.0 as at 8 or 7, whereas others, such as antibiotic wastes, are greatly affected by pH values of 9, or even 8, and oxidize better at pH 7 or lower.

The effect of initial pH value on the rate of oxidation of diluted spent sulfite liquor was studied. The original sulfite liquor contained 10 per cent solids and had a 5-day B.O.D. of 19,000 p.p.m. It was diluted 1:20, nutrients were added, pH was adjusted from 4 to 7, and it was seeded with previously adapted seed. The results (Table I) show that as the initial pH increased from 4 to 7 the oxygen utilization increased and that the final pH in each case was higher than the initial value.

The effect of initial pH on the oxidation of 1,000 p.p.m. ethyl acetate is indicated in Table II. The initial pH was varied from 4 to 10 using samples seeded with 10 per cent settled sewage; sufficient nitrogen and phosphorus were added for the requirements. All samples with an initial pH of 8.0 or lower

TABLE III.—Effect of Buffer on the Rate of Oxidation[1] of 1,000 P.P.M. of Ethyl Acetate

Time (days)	O_2 Utilized (p.p.m.)	
	Buffered	Not Buffered
1	155	140
2	860	355
3	1,040	820
4	1,140	900
Final pH	7.8	3.9

[1] Results expressed as p.p.m. O_2.

had a final pH value of 3.0 to 3.6 after 4 days. Apparently, acid intermediates were produced during oxidation, in addition to CO_2. The carbon dioxide produced cannot be responsible for the lowering of the pH value, as complete absorption of the CO_2 was obtained by providing an alkali in the reaction vessel. Despite the drop in pH values, the highest oxygen utilization took place at pH values of 7 and 8 and not at pH 9 or 10 which are more inimical to the oxidation of ethyl acetate than an initial adjustment to 7 or 8 with a final pH of 3.3.

To prevent the decrease in pH during oxidation, a portion of 1,000 p.p.m. ethyl acetate was buffered with potassium phosphate to a pH of 7.7. Another portion remained unbuffered. Required amounts of nitrogen and phosphorus were added, the solutions were seeded with 10 per cent settled sewage, and the oxygen utilization was determined by the direct method. The results (Table III) show that in the unbuffered mixture the pH value decreased to 3.9 after 4 days, whereas in the buffered mixture the pH was at 7.8 after 4 days. The oxygen utilization was decidedly higher in the buffered mixture.

Effect of Nutrient Addition

The nitrogen requirements of a number of industrial wastes were studied by the direct method. Each waste was adjusted to pH 7.0 and seeded with 2 per cent sewage. Then various quantities of nitrogen were added (as NH_4Cl) and the oxygen utilization during a 5-day incubation period was determined in the Sierp apparatus. The daily quantities of oxygen utilized by addition of various quantities of nitrogen to board mill white water are illustrated in Figure 2. The control without additions of nitrogen utilized oxygen at a slow rate with a total of 330 p.p.m. in 5 days, whereas addition of 15 p.p.m. of nitrogen increased the oxygen utilization greatly, with an oxygen utilization of 885 p.p.m. in 5 days. The addition of 30 p.p.m. of nitrogen caused a slight additional increase of oxygen utilization over the 15-p.p.m. addition; the values obtained with 45 p.p.m. nitrogen were identical with those obtained with 30 p.p.m. The required amount of nitrogen addition is estimated to be slightly higher than 15 p.p.m., possibly in the neighborhood of 20 p.p.m.

Similar studies were made with dextrose, rice-cooking waste, rope cook liquor, and waste from candied fruit production. The detailed results are not given, but a summary of the nitrogen requirements based on these studies is shown in Table IV, which includes the nitrogen present originally in the waste, the additional nitrogen required, the oxygen utilized, and the ratio of

TABLE IV.—Nitrogen Requirements for the Oxidation of Several Industrial Wastes

Waste	Nitrogen (p.p.m.)		O_2 Utilized[1] (p.p.m.)	O_2 Utilized : N Ratio
	In Original Waste	Added		
1,500 p.p.m. dextrose	0	40	880	22
Rice cook water	30	20	1,020	20
Board mill white water	35	20	940	17
Rope cook liquor	2	40	780	18
Candied fruit waste	6	35	800	19

[1] In 5 days.

the oxygen utilized to the sum of the nitrogen present in the waste and the added nitrogen.

With the exception of dextrose, all wastes contained initially some nitrogen. It is of interest that even dextrose without addition of supplemental nitrogen manifested some oxygen utilization (145 p.p.m. in 5 days) for a 1,500-p.p.m. solution of dextrose. The oxygen utilization of dextrose and the other nitrogen-deficient wastes employed in these experiments increased with increasing supplemental additions of nitrogen up to a given point. Further additions did not increase the oxygen utilization. This optimum point of supplemental addition of nitrogen plus the nitrogen contained in the original waste (if present) represents the actual requirement for biochemical oxidation of the organic substances. The oxygen utilized with optimum quantity of nitrogen (added plus originally present) shows ratios varying from 22 to 17 for various organic wastes tested. These examples illustrate how readily the nitrogen deficiency (if any) and the quantity of nitrogen required to make up the deficiency can be determined for maximum biochemical oxidation of any waste.

Effect of Substrate Concentration

The question often arises as to whether the concentration of organic matter *per se* plays a role in the oxidation. This is not merely an academic question, but has some important applications. In the determination of B.O.D. by the dilution method, various concentrations of a given sample are tested and the results are assumed to be independent of the concentration of the organic matter in the sample tested. It is true that the differences in the concentration are limited by virtue of the limited oxygen supply, but the additional question arises as to whether the oxidation rates as obtained in the highly diluted samples apply equally well when the same waste is treated without dilution under otherwise identical conditions. If the dilution affects the rate of oxidation, the projection of the results to oxidation rates in a stream will be in error, except when dilution in the stream happens to be of the same order as in the laboratory B.O.D. technique.

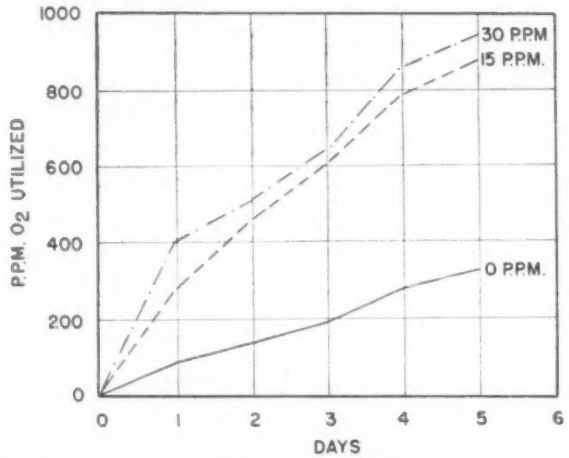

FIGURE 2.—Oxygen utilization of board mill white water supplemented with different quantities of nitrogen.

TABLE V.—Deoxygenation Constants of Sewage by the Standard Dilution and Direct Methods

Sample Number	Standard Dilution Method				Direct Method			
	5-Day B.O.D. (p.p.m.)	Ult. B.O.D. (p.p.m.)	k	1-Day 5-Day B.O.D.	5-Day B.O.D. (p.p.m.)	Ult. B.O.D. (p.p.m.)	k	1-Day 5-Day B.O.D.
1	167	186	0.248	0.475	189	213	0.265	0.490
2	95	110	0.233	0.505	108	118	0.228	0.515
3	81	99	0.244	0.455	95	110	0.234	0.465
4	60	71	0.240	0.485	71	80	0.234	0.495
5	135	143	0.294	0.480	156	170	0.271	0.520
6	300	336	0.239	0.520	333	376	0.263	0.545
7	67	71	0.278	0.520	76	84	0.285	0.515
8	128	137	0.317	0.560	149	158	0.318	0.535
Av.	129	144	0.262	0.507	147	164	0.262	0.514

A study was accordingly made concerning the effect of sewage concentration on the rate of oxidation and oxygen demand as determined by the standard dilution method and by the Warburg apparatus. The k and L values were calculated by the Thomas method (13) from determinations over a 5-day period. The results from eight domestic sewages, as obtained from a series of dilutions by the standard excess dissolved oxygen method, are compared (Table V) with those obtained by the Warburg method without dilution.

Both the 5-day and ultimate oxygen utilization values by the Warburg method were, on an average, 14 per cent higher than the B.O.D. values obtained by the standard dilution method. The rate of oxidation, however, is independent of sewage concentration and the k values obtained by each method averaged 0.262. Gotaas (8) obtained an average k value, at 20° C., of 0.19 with considerable variations with different sewages. Ruchhoft, Placak, and Ettinger (12) found the most frequent k values to be 0.16 to 0.20 in 45 samples of sewage. Moore, Thomas, and Snow (11), using 7-day series of observations, obtained k values of 0.2 for several domestic sewages. The higher values obtained in the present study may be due, in part, to the fact that the sewages were filtered through cotton, removing the coarser and less readily oxidizable organic material.

The problem was studied in still another way. Various concentrations of four different sewages were placed in the Warburg apparatus, the oxygen utilizations in 5 days determined, and the results compared with the B.O.D. values obtained with the standard dilution method (Table VI). The concentration of sewage in the Warburg series varied from 100 to 10 per cent. With decreasing sewage concentration the oxygen utilization decreased. The minimum values with the Warburg apparatus were obtained with 10 per cent concentration and the values obtained at this concentration corresponded more closely to the B.O.D. obtained by the standard dilution method.

TABLE VI.—Five-Day Oxygen Demand[1] of Four Sewages at Different Concentrations as Determined by the Direct Method in Comparison with the Standard Dilution Method

Sample	Sewage Concentration (%)						Standard Dilution
	100	70	50	40	20	10	
1	156	151	149	148	141	128	135
2	76	77	76	73	70	62	67
3	333	332	333	331	321	295	300
4	150	148	147	146	144	142	128

[1] Results expressed as p.p.m. O_2 utilized.

The effect of substrate concentration on the oxygen utilization of spent sulfite liquor was studied to determine whether the concentration of the substrate, as such, had an effect on the oxygen utilization. Various dilutions of sulfite liquor waste were made from 1:20 to 1:2, nutrients were added, the pH was adjusted to 7.0, and the specimens were seeded with previously adapted seed. The oxygen utilization values, in p.p.m. in 21 hr. on the basis of the original undiluted sample, were as follows:

Dilution	O_2 Util. (p.p.m.)
1:20	19,400
1:8	19,600
1:4	19,720
1:2	20,600

Within the dilution range employed there was no significant difference in the oxygen utilization. The 5-day dilution B.O.D. of this waste was 23,000 p.p.m. at a dilution ratio of 1:10,000. About 87 per cent of the 5-day oxygen demand at 1:10,000 was exerted with adapted seed in 21 hr. at much higher concentrations of substrate. With a 5-day incubation period by the direct method it is reasonable to assume that an oxygen demand equal to that exerted by the dilution method at 1:10,000 would have been obtained and, hence, over a range of dilutions from 1:2 to 1:10,000 there would be little, if any, effect on oxygen utilization. The waste can be oxidized as effectively without dilution as with extreme dilution, provided sufficient oxygen can be supplied to meet the high rates of demand exerted without dilution.

Effect of Sewage Seed Volume and Source

A study was made of the effect of source and volume of seed on the oxygen utilization of industrial waste by the direct method. In all cases the pH values of the wastes were adjusted to 7.0 and domestic settled sewage from a number of municipal plants was used for seeding. Where the waste was deficient in nitrogen and phosphorus, it was corrected by the addition of NH_4Cl and KH_2PO_4.

For the first experiments, a synthetic substrate was selected because such a substrate would not contain as many organisms as a waste; therefore, the effect of additions of different quantities of seed could be demonstrated more readily. The substrate contained 1,000 p.p.m. each of dextrose and peptone. Sewage from three different municipalities not containing appreciable amounts of industrial wastes was studied. The

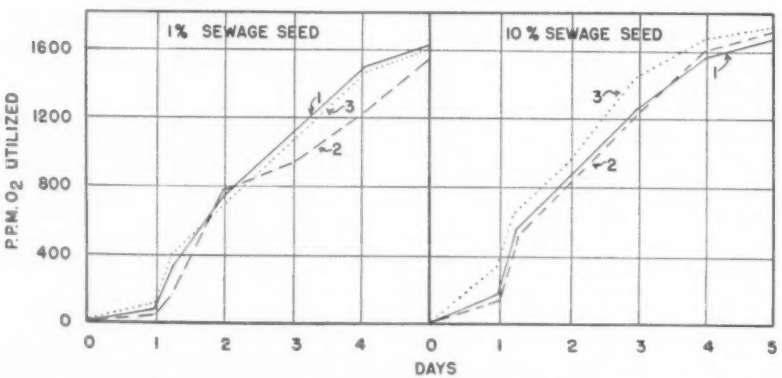

FIGURE 3.—Effect of source and volume of sewage seed on the oxidation of dextrose and peptone substrate (1,000 p.p.m. each).

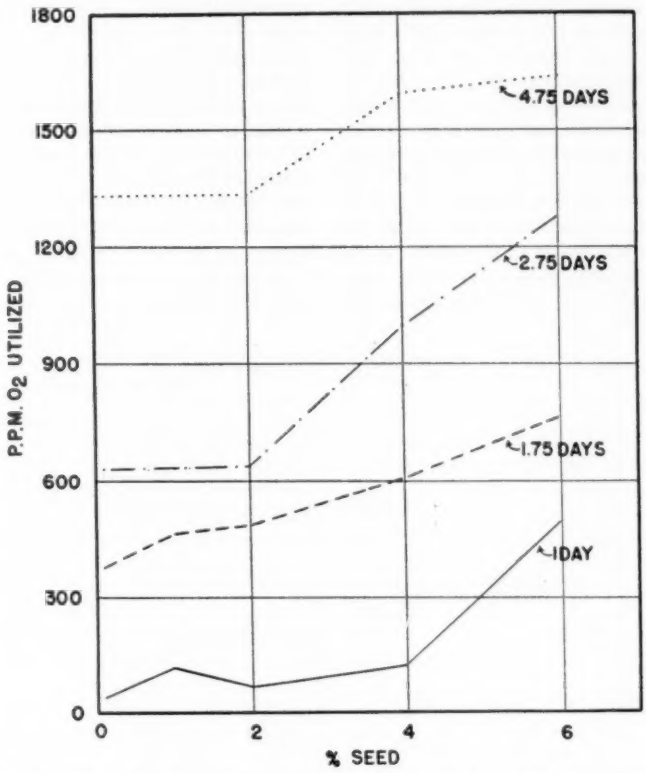

FIGURE 4.—Effect of volume of sewage seed on the oxidation of dextrose and peptone substrate (1,000 p.p.m. each).

substrate was inoculated with 1 and 10 per cent of these sewages by volume. The rate of oxidation of the substrate was measured in the Sierp apparatus over a 5-day period. The oxygen demand of the sewages was determined separately by the same technique, and corrections were made for the oxygen demand exerted by the sewage in the substrate. The oxygen demands due to the substrate seeded with three sewages at 1 and 10 per cent volume concentrations are shown in Figure 3. The results indicate the general trend with slight variations in the oxygen demand exerted due to seeding with sewage obtained from different sources. The differences were more pronounced with shorter periods of incubation and there was a lag of one day, which was not overcome, even with 10 per cent seeding. The higher seeding volume resulted in somewhat higher oxygen consumptions throughout the 5-day period, but the differences became smaller with the longer period of incubation. The average oxygen utilization values for the three sewages used as seed during a 1-day incubation period were 83 p.p.m. for 1 per cent dilution and 218 p.p.m. for 10 per cent dilution; during the 5-day period the corresponding values were 1,580 and 1,690 p.p.m., respectively.

The oxygen demand exerted during one day was more than 1.5 times greater with 10 per cent seed than with 1 per cent. After 5 days the substrate seeded with 10 per cent sewage gave only 7 per cent higher values than those seeded with 1 per cent. The magnitude of variation for the 1-day oxygen utilization between 1 and 10 per cent inoculations is significant, while the 7 per cent variation for the 5-day period is very close to the confidence limits of the Sierp apparatus, which have been shown (6) to be 6 per cent.

An additional experiment on the effect of seeding dextrose peptone substrate (1,000 p.p.m. each) with a given sewage at concentrations varying from 0.1 per cent to 6 per cent was conducted. The results (Figure 4) indicate, in general, that the oxygen consumption increases with increasing concentration of seed up to 6 per cent. For shorter periods of incubation (1, 1.75, and 2.75 days) there is no indica-

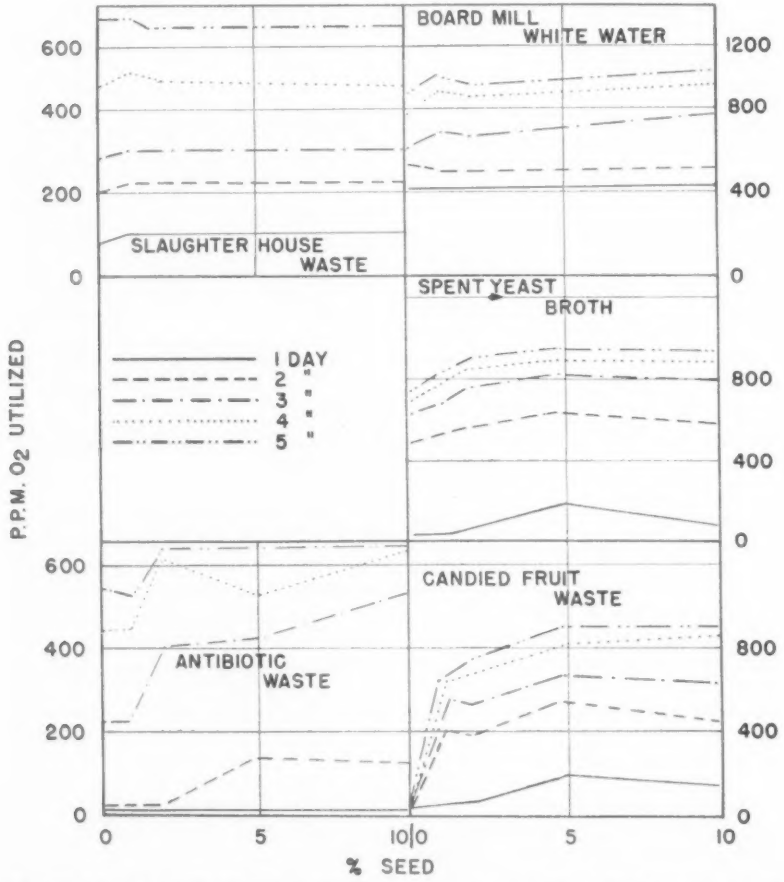

FIGURE 5.—Effect of volume of sewage seed on the oxidation of six industrial wastes.

tion that maximum utilizations have been obtained, even with 6 per cent seed. However, with 4.75 days of incubation the oxygen demands exerted with 4 and 6 per cent seed are nearly alike. The values obtained in this experiment correspond favorably with those obtained from the previous experiments with the same substrate concentration seeded with 1 and 10 per cent sewage.

It should be noted that concentration of the substrate also has a bearing on the quantity of seed and that there is some relationship between food concentration and the amount of seed required.

The effect of seeding with various volumes of sewage on the oxygen demand of six industrial wastes was determined. All wastes were neutralized to pH 7.0, seeded with sewage varying from 0 to 10 per cent by volume, and the oxygen utilization determined by the Sierp method. The results are presented in Figure 5. In the case of slaughterhouse waste, variation in sewage volume produced no significant differences in the oxygen utilization. Even without artificial seeding the oxygen utilization was practically the same as with 10 per cent seeding. This is equally true with short and long periods of incubation. It appears that this waste is sufficiently contaminated with microorganisms capable of oxidizing the organic matter present and additional seeding is not required. Similar results were obtained with board mill white water and spent yeast broth.

Entirely different results were obtained with antibiotic wastes and waste produced from candied fruit manufacture. Antibiotic waste did not utilize any oxygen during the first day, irrespective of the volume of sewage seed added. During the second day appreciable quantities of oxygen were utilized with a seed concentration of 5 per cent and higher, but none at lower concentrations. With longer periods of incubation the differences between low and high concentrations of seed became narrower, but were not obliterated. The need for seed is even more pronounced in waste produced from candied fruit manufacture, with no oxygen utilization recorded over a period of 5 days without artificial seeding. A 0.1 per cent seed increased the oxygen utilization greatly; beyond 5 per cent seed no further increase in oxygen utilization was observed. Although no bacterial counts were made of the original wastes, it is likely that two types of response to seeding are related to the bacteria in the waste.

The effect of various sewage seed volumes on the oxidation of 1,000 p.p.m. of ethyl acetate was studied. The pH value was adjusted initially to 7.0 and sufficient nitrogen and phosphorus were added to meet the requirements. The sewage seed added represented 1, 5, 10, and 25 per cent of the total volume. The results obtained from 1 and 25 per cent seed concentrations were as follows:

Incubation Period (days)	Oxygen Utilized (p.p.m.)	
	1% Seed	25% Seed
1	45	140
2	185	565
3	470	735
4	650	765

Again, oxygen utilization was higher with the greater concentration of sewage used and this effect was most pronounced with shorter periods of incubation.

Similar studies were made with spent sulfite liquor. A 1:20 dilution of this waste was seeded with sewage in concentrations varying from 90 to 1 per cent with the usual adjustment of pH value and supplying the nutritional requirement. The short period oxygen utilizations increased with increasing seed concentration up to 60 per cent, but the 5-day oxygen utilization values were practically the same within this range of seed concentrations.

Similar results were obtained from a study of the effect of sewage seed

concentration on the oxidation of rope cook waste.

Effect of Seed Adaptation on the Oxygen Utilization of Wastes

In the previous section, results of initial seeding of wastes with various volumes of sewage were presented. Irrespective of the volumes of seed used, it seems probable that maximum oxygen utilization was not exerted with certain wastes because the flora in the sewage used as seed did not contain sufficient numbers of microorganisms to oxidize wastes of such different natures.

In the following experiments, after a particular waste was oxidized with an initial inoculation of sewage, a part of the treated waste was used successively to oxidize fresh portions of the same waste. In all cases the environmental factors of pH and nutritional requirements were optimal.

The effect of seed adaptation on the oxidation of 500 and 1,000 p.p.m. of phenol was studied starting with sewage as seed and with successive transfers. At each step the seed represented 50 per cent of the total volume. The results (Figure 6) show a lag period of 3 to 4 days with the initial sewage seed in 500 p.p.m. phenol. On the first transfer the lag period was reduced to 1 day; on the second transfer it was completely eliminated. On the second transfer the same quantity of oxygen was utilized in 1 day as with the initial sewage seed in 6 days. With 1,000 p.p.m. of phenol there was a lag period of nearly 9 days with the initial sewage seed. This period was reduced with each successive transfer until the third, when it was completely eliminated. The quantity of oxygen utilized on the third transfer was equal after only 2 days to that utilized with initial sewage seed after 10 days. Apparently, with properly adapted seed a phenol concentration of 1,000 p.p.m. can be oxidized readily.

The effect of successive increases in the concentration of phenol on its oxidation was studied. Adapted seed obtained from the oxidation of 500 p.p.m. phenol was used to inoculate a phenol solution of 1,000 p.p.m. After 5 days

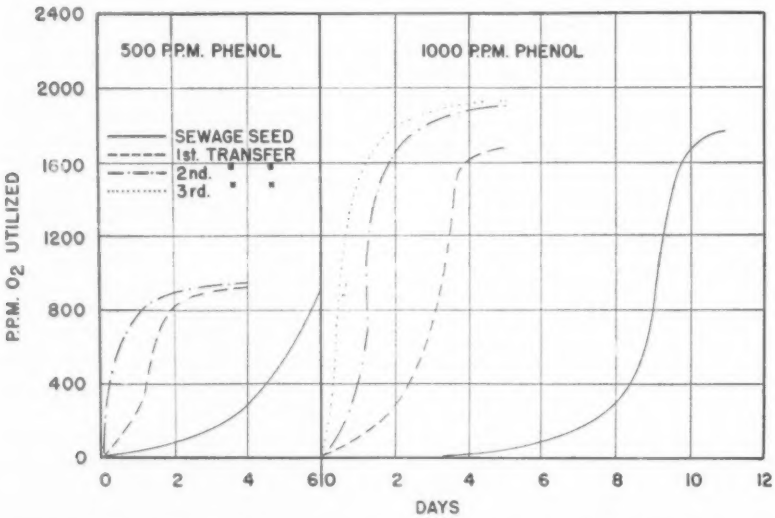

FIGURE 6.—Effect of seed adaptation on the oxidation of 500 and 1,000 p.p.m. of phenol.

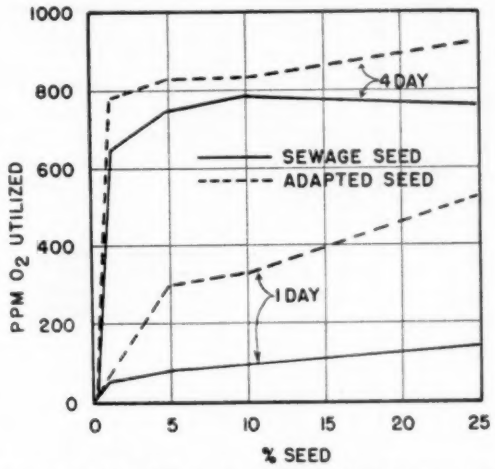

FIGURE 7.—Effect of seeding on the oxidation of ethyl acetate with various concentrations of sewage and adapted seed.

a portion of this oxidized material was used to seed 1,500 p.p.m. phenol solution and the process repeated with 2,000 p.p.m. phenol. At each step equal volumes of seed were used. The results, expressed as percentage of the theoretical oxygen demand satisfied, were as follows:

Incubation Period (days)	Phenol Concentration (p.p.m.)		
	1,000	1,500	2,000
1	15	28	19
2	69	73	34
3	77	78	54
4	—	79	80
5	80	80	86

When the phenol concentration was increased from 500 to 1,000 p.p.m. there was a 1-day lag before active oxidation, but this was overcome after 2 days, so that 77 per cent of the theoretical oxygen requirement was exerted in 3 days. When the phenol concentration was increased to 1,500 p.p.m. the rate of oxidation increased somewhat. With a further increase of phenol to 2,000 p.p.m. the oxidation values obtained up to 3 days were lower than with 1,500 p.p.m. phenol. The results indicate that phenol concentrations up to 2,000 p.p.m. can be readily oxidized.

The effect of seed adaptation on the oxidation of ethyl acetate is illustrated in Figure 7. Only the results from 1-day and 4-day incubation periods are included. During a 1-day incubation period the oxidation was low with all concentrations of unadapted sewage seed, but was greatly increased at all concentrations of adapted seed employed. The differences between adapted and unadapted seeds are much smaller with a 4-day incubation period.

Figure 8 presents the results of increasing concentration of adapted seed on the oxidation of spent sulfite liquor in 1:2 concentration. Maximum benefit is derived from the use of 5 to 10 per cent adapted seed; higher seed concentrations do not bring about commensurate increases in oxygen utilization. The differences in the oxygen utilization decrease with increasing periods of incubation. The 5-day dilution B.O.D. of the undiluted spent sulfite liquor is 23,000; therefore, nearly complete oxidation was obtained of the 1:2 dilution of this waste with 5 to 10 per cent seed in 2 days.

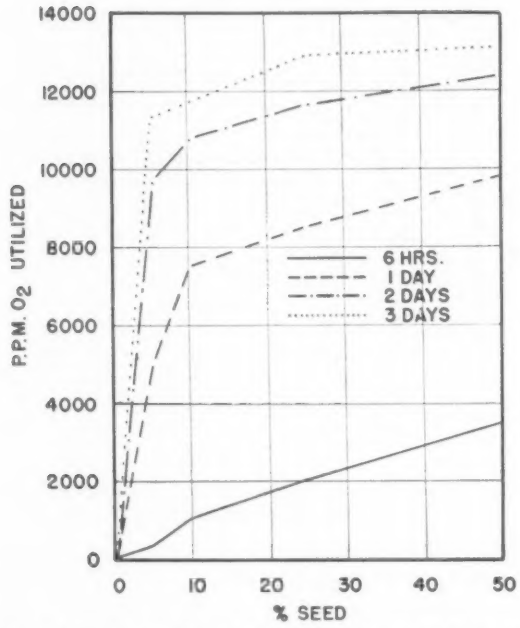

FIGURE 8.—Effect of various concentrations of adapted seed on the oxidation of waste sulfite liquor (diluted 1:2).

The effect of addition of various volumes of sewage and adapted seeds to rope cook liquor for a 2-day incubation period is shown in Table VII. The cook liquor was diluted 1:2 before use. With shorter periods of incubation, increasing volumes of sewage seed increase the oxygen utilization, whereas with longer periods of incubation the effect of increasing concentrations becomes less. With adapted seed the oxidation of rope cook liquor is greatly accelerated in comparison with the oxidation obtained with sewage seed and the effect of increasing concentration of seed is not so pronounced.

TABLE VII.—Effect of Addition of Various Volumes of Sewage and Adapted Seed on the Oxidation[1] of Rope Cook Liquor

Days	Seed Concentration (%)							
	50		25		10		5	
	Sewage	Adapted	Sewage	Adapted	Sewage	Adapted	Sewage	Adapted
1	345	990	215	895	280	760	120	720
2	665	1,425	610	1,310	585	1,225	490	1,250
3	1,090	—	1,025	—	975	—	840	—
4	1,330	—	1,330	—	1,280	—	1,240	—
5	1,545	—	1,610	—	1,560	—	1,520	—

[1] Results expressed as p.p.m. O_2 utilized.

Discussion

On the basis of results obtained, it appears that there is a wide range of pH values for the oxidation of various industrial wastes—that is, the optimum pH is not confined to a narrow point, hence the pH value does not need to be carefully controlled. Some wastes, such as spent yeast broth, slaughterhouse wastes, and candied fruit wastes, have an optimum pH range of 5 to 9. Others, like board mill white water and rope cook liquor, have an optimum pH range from 6 to 9. Still others, like the antibiotic and sulfite liquor waste, have an optimum range from 5 to 7. It is noteworthy that the effect of pH is more pronounced and the width of the optimum pH range is more restricted with shorter periods of incubation. There is a general tendency during oxidation for the pH to shift toward neutrality from both the acid and alkaline ranges. In certain cases, however, such as ethyl acetate, this generalization does not apply and the acid as well as the alkaline ranges all tend to become more acid. This is probably due to the production of acid intermediate products in addition to carbon dioxide. The changes in pH value cannot be attributed to the production of carbon dioxide as a result of oxidation, because in all cases this gas was effectively absorbed by the alkali. The buffer value of the waste has a decided effect on the changes of pH value. The decrease in pH value of ethyl acetate during oxidation can be arrested by buffering the substrate, and increased rates of oxidation can thereby be obtained.

The number of wastes studied has been limited, but can readily be extended by using the manometric techniques employed. More information of general value can be obtained in regard to the effects of pH value on the oxidation rates of industrial wastes, as well as more specific information to predetermine the adjustment of pH value of a particular waste to obtain maximum rates of oxidation for treatment. Such studies could result in considerable economies in cost of acids or alkalies used for pH adjustment of a particular waste. It may be found, as a number of wastes in these studies have shown, that for a waste with an original acid reaction, adjustment to a pH value of 7 may not be necessary and that equally efficient oxidation may be obtained by adjustment to a pH of 5 or 6. A similar situation may exist in respect to wastes with an original pH of 9 or 10.

The studies in respect to the nutritional requirements of industrial wastes have confirmed the generally accepted view that oxidation is affected by a deficiency of nitrogen and phosphorus, as well as the fact that the optimum B.O.D. to nitrogen ratio is around 20 to 1. The ratios obtained in the study have varied from 17:1 to 22:1. The important point in this respect is the convenient way in which the existence of a nutritional deficiency, as well as the quantity of supplemental nitrogen and phosphorus necessary to obtain optimum oxidations, may be determined by the direct methods. All that is necessary is to add increasing quantities of nitrogen. The quantity of nitrogen added beyond which no appreciable increase in the oxidation rate is obtained represents the requirement. A waste is seldom completely devoid of these nutritional elements, but usually contains a certain amount of nitrogen and phosphorus. It is, therefore, a question of determining how much more must be artificially added to obtain optimum oxidation. If the established ratio of 20 to 1 is used, it becomes necessary for economic reasons to determine the nitrogen and phosphorus content of the original waste and supplement them by artificial additions. This procedure is more laborious and, in some cases, may be misleading. For instance, in taking account of the nitrogen content of the original waste, should the ammonia nitrogen be taken into consideration or

the total organic nitrogen? If the latter is used the question arises whether the organic nitrogen can be rendered available sufficiently rapidly for assimilation by bacteria. The use of the direct method eliminated all these uncertainties, as the requirements are not determined by chemical analysis or calculation, but under actual experimental conditions of oxidation.

The question of the effect of substrate concentration on oxidations has been approached in various ways. The oxygen demands of eight domestic sewages were determined by the standard dilution method and those of the undiluted sewages by the direct method. The results show that the oxygen demands of the undiluted sewages were somewhat higher when determined by the direct method than those obtained by the standard dilution method. This is true of both the 5-day demands and the L values obtained from the daily observations up to 5 days. The average k values as obtained by the two methods (standard dilution and direct method) were identical. The higher oxygen demand values obtained were greater than the experimental precision for the two methods. The differences in the oxygen demand values with the standard dilution and direct methods may be attributed to (a) differences in the conditions under which the two methods operate, or (b) actual differences due to the substrate concentration. That the differences in the test conditions of the two methods are not responsible for the higher oxygen demands observed is shown by the oxygen demand values obtained by the direct method with various dilutions of sewages (Table VI). A progressively increasing oxygen demand was exerted with increasing concentration of sewage from 10 to 100 per cent by the direct method, and the values obtained from the lower concentration compared favorably with those obtained by the standard dilution method. In contrast with these results, variations in the dilution of spent sulfite liquor from 1:20 to 1:2 had little effect on the oxygen demand exerted when seeded with adapted seed. It might be suggested that the discrepancy may be the result of dilution of sewage by reduction of food concentration and number of organisms, thereby affecting the rate of oxidation.

The effect of seeding was studied from the following standpoints: (1) origin of the sewage used for seed, (2) volume of seed, and (3) the effect of adaptation of seed. The studies were based on the oxygen utilization as measured by the direct methods. Oxygen utilization of 1,000 p.p.m. dextrose peptone substrate when seeded with a given volume of domestic sewage obtained from different sources, showed only slight variations during a 5-day period, but increasing the volume of sewage seed increased the oxygen demand with increasing volumes. The effect of seed volume is more pronounced with shorter periods of incubation than with longer periods. It appears that with a 5-day incubation period a minimum volume of sewage seed of 4 to 6 per cent is required, above which there is no relationship between the volume of seed and the measured oxygen utilization.

The effect of various volumes of sewage seed on the oxygen demand of 6 different types of industrial wastes is manifested by different responses. Certain wastes, such as slaughterhouse, board mill white water, and spent yeast broth, can be oxidized as readily without seeding as with large volumes of seed. With these wastes, equally high oxygen demand values are obtained with no seeding, or with very low seeding volumes, irrespective of the period of incubation. Others, such as antibiotic and candied fruit wastes, show little oxidation without seeding, and the oxidation increases to a maximum with increasing seed volume up to a certain maximum. These different responses can be attributed to the

degree of bacterial contamination of the original wastes.

The adaptation of the seed plays an important role in the oxidation of industrial wastes. Two somewhat related aspects of adaptation can be recognized. The first pertains to the adaptation of seed to organic wastes with toxic properties; the second, to organic wastes without toxic properties. The differences in the response to adaptation between these two types of waste are quantitative and not qualitative. Toxic organic materials with an unadapted seed will manifest at first a greater lag and the response to adaptation will be greater than with a nontoxic waste. Adaptation will permit the oxidation of greater concentrations of the toxic material than would have been possible with the initial unadapted seed, but eventually a concentration level will be reached beyond which the material cannot be oxidized with adapted seed. The principles underlying the process of adaptation, as well as the factors influencing the oxidation of industrial wastes, were previously discussed by Heukelekian (10). The present work confirms and illustrates these principles. The experimental work dealing with the effect of seed adaptation on the oxidation of phenol illustrates what might be accomplished in developing a micro-flora capable of oxidizing a toxic substance and indicates the maximum concentration limits. In an earlier publication (9) it was shown that as the concentration of phenol added to sewage was increased there was an increased lag period, which was most pronounced at 1,000 p.p.m. phenol concentration. In the present study similar results were obtained. With unadapted sewage seed and 500 p.p.m. phenol a lag period of 3 to 4 days was obtained; with 1,000 p.p.m. phenol the initial lag period was 9 days. On successive transfers the lag period was greatly reduced, until with 500 p.p.m. phenol there was no lag evident after the second transfer and with 1,000 p.p.m. none after the third transfer. With successive increases in the concentration of phenol using adapted seed, 80 per cent oxidation of 2,000 p.p.m. of phenol was obtained in 4 days. Similar results were obtained (7) in the oxidation of formaldehyde. Ettinger and Ruchhoft (4) obtained similar effects of adaptation on the oxidation of phenol, but at much lower concentrations of phenol (1 p.p.m.)

The results for the oxidation of ethyl acetate with and without adapted seed illustrate the influence of seed adaptation on the oxidation of a nontoxic compound. In this case the influence of adaptation was most pronounced with short periods of incubation, but even with adapted seed only partial oxidation was obtained in 1 day as compared with the oxidation obtained with or without adapted seed in 4 days.

Regarding the oxidation of wastes by the use of properly adapted seed, it is noted that the oxidation of certain wastes, as exemplified by sulfite liquor and rope cook liquor, is greatly increased by the use of adapted seed and that there is an optimum volume of adapted seed beyond which no additional benefit is derived.

The phase of the work dealing with the effect of origin and volume of adapted and unadapted seed illustrates again the value of the direct methods for evaluating the influence of these factors on the oxidation of industrial wastes. It constitutes the preliminary phase of a study to establish the feasibility of treatment by biological oxidation methods and the conditions necessary to obtain maximum rates of oxidation.

Summary and Conclusions

With the use of the direct methods of oxygen utilization, the influence of various factors—such as pH value; nutritional deficiency and requirement; substrate concentration; and origin, volume, and character of seed—on the

oxidation of a number of industrial wastes has been studied. The results warrant the following conclusions:

1. Adjustment of initial pH value between 6 and 8 prevents the initial pH from affecting the oxidation. There is considerable range of optimum pH values. For some wastes this range is wider than for others; for some it is more to the alkaline side, whereas for others it is on the acid side of neutrality. The effect of pH is more pronounced and the range more restricted during shorter periods of incubation. The pH values tend to gravitate toward the neutral point from both the acid and alkaline sides. In poorly buffered wastes the tendency is toward the acid side, especially when acid intermediate products are pronounced.

2. To prevent nitrogen deficiency from limiting the rate and extent of oxidation of wastes, nitrogen readily available to microorganisms must be added to satisfy a B.O.D.:N ratio between 17:1 and 22:1.

3. The reaction velocity constant, k, for the oxidation of settled sewage is the same for the standard dilution and direct methods.

4. The oxygen demand values obtained by the direct method for sewage and wastes are somewhat higher than for the standard dilution method, the increase being caused apparently by the higher concentration of organic matter present when the direct method is used.

5. The origin of sewage (domestic) used for seeding a dextrose peptone substrate had a minor influence on the rate of oxidation.

6. The oxidation of wastes (such as slaughterhouse, board mill white water, and spent yeast broth) which contain large numbers of organisms is not affected by variations in sewage seed volume and origin. With other wastes (antibiotic and especially candied fruit wastes) little oxidation is obtained without seeding.

7. Where the rate of oxidation of a waste is affected by the volume of sewage used as seed, this effect is most pronounced at the outset and is reduced or eliminated with further incubation.

8. By adaptation, a seed material is produced that can readily oxidize phenol concentrations as high as 2,000 p.p.m. With unadapted seed prolonged initial lag periods occur, which increase with the concentration of phenol.

9. The initial rate of oxidation of ethyl acetate, waste sulfite liquor, and rope cook liquor is increased by an increase in sewage seed or adapted seed volume, the effect being minimized with increased periods of incubation.

10. Waste sulfite liquor and rope cook liquor are non-toxic and are amenable to biological treatment.

Acknowledgment

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SUMMARY REPORTS ON RARITAN POLLUTION

In two recently published summary reports on the Raritan River, the Middlesex County (N. J.) Sewerage Authority has made available the results of investigations undertaken for it on the extent and abatement of pollution of the river, its tributaries, and Raritan Bay.

One of the reports, by Willem Rudolfs, chairman, Department of Sanitation, Rutgers University, and Alfred H. Fletcher, director, Division of Environmental Sanitation, New Jersey State Department of Health, deals with the status of pollution of the Raritan River and Bay and the effect of discharging into the Bay treated mixed effluents from a single large treatment plant. The general conclusions reached by the report are as follows:

1. Gross pollution of the Raritan increases progressively downstream, reaching the maximum below New Brunswick. Cross pollution in the South River (a tributary) is greater than anywhere in the Raritan.

2. Bacterial pollution of Raritan Bay is relatively high, originating primarily in the Raritan River, although Arthur Kill has a deleterious effect on the bay waters.

3. Nearly all municipal and industrial effluents do not meet present requirements and certainly not future requirements.

4. Collection of all effluents, treatment in a single plant, and discharge about 2 mi. out in the bay would eliminate pollution of the river and its tributaries, improve bay-water conditions at beaches and shellfish areas in the upper bay, and not noticeably affect the volume or the salt concentration of the river water.

The second report, by Metcalf & Eddy and Elson T. Killam, consulting engineers to the Authority, estimates the initial cost of a proposed trunk sewer, treatment plant, and bay outfall as $30,000,000, with an annual operating cost of $1,400,000 during the first five years. Financing of the project would be by revenue bonds secured by a service charge based on an equitable formula. It is estimated that industry would pay about 65 per cent and municipalities about 35 per cent of the total annual cost.

THE OPERATOR'S CORNER

CONDUCTED BY HERBERT P. ORLAND

GET IN THE SCRAP!

Aimed to help increase the current dangerously low iron and steel scrap inventories in U. S. steel mills, the National Production Authority has distributed a booklet, "Scrap for Steel Mills and Foundries for Defense," to more than 200,000 executives of business, industry, and trade associations. In a foreword to the booklet, DPA Administrator Manly Fleischmann says, "I don't believe we are confronted with a more critical problem than the iron and steel scrap recovery program."

The booklet emphasizes that record-breaking steel production and large-scale expansion of production capacity has reduced scrap inventories of mills and foundries to a new all-time low. If the nation is to achieve its 1951 goal of 110,000,000 tons of steel ingots and castings, 36,000,000 tons of purchased heavy industrial scrap must be found.

The main effort in getting the scrap to the places where it will do some good is directed at getting "dormant" scrap —obsolete machinery and equipment, tools, jigs, dies, and fixtures, including items that are broken, worn beyond repair, dismantled, abandoned, or in need of parts no longer obtainable—into normal channels of scrap return. Besides emergency inspection and inventory of all heavy steel, it is extremely important that every plant, large and small, appoint someone with authority to clean out dormant scrap and to be responsible for the scrap collection on a continuous good-housekeeping job. Large plants should have a salvage committee with authority to make decisions. Among the functions of such a committee would be to search all plants and properties for dormant scrap, survey potential wrecking and dismantling projects that will produce scrap, and make disposition of all production and dormant scrap as quickly as possible.

Putting scrap collection on a housekeeping basis, besides increasing the supply of iron and steep scrap, will provide a chance for inventory write-off, improve safety conditions, clear valuable space, and possibly reduce insurance rates. It is suggested that an organized permanent salvage program be made a top-management responsibility. To us, this makes extremely good sense, not only for industrial management, but also for the management of sewage and industrial wastes plants.

Scrap prices are regulated and controlled by the Office of Price Stabilization. Therefore, sale of your scrap through normal scrap dealer channels is on a standard basis.

Your plant may be hiding a potential plate for a ship, a complete car, or several shells and bombs. Let's get the scrap into the scrap!

H. P. O.

WINTER MAINTENANCE *

By D. L. McLean

Superintendent, Greater Winnipeg Sanitary District, Winnipeg, Man., Canada

Although winter maintenance has obvious disadvantages, these disadvantages can be overcome or considerably reduced by proper attention to the selection and use of equipment, materials, and methods. In fact, there are many instances where winter maintenance, through some peculiar circumstance or condition, may have advantages.

Reduction and Elimination of Disadvantages

The disadvantages of winter maintenance are caused by frost or cold, snow, ice, and condensation. Equipment, materials, and methods of overcoming or reducing the disadvantages imposed by winter include the following:

1. Machines, trucks, cars and other equipment can be winterized by oils or grease to meet local winter temperatures.

2. Where frozen ground must be excavated, the frost can be broken by fire. For example, a 6-in. thick slab containing 3 cu. yd. of concrete had to be poured on ground frozen to a depth of 2 ft.; 6,000 of Souris slack, 4 bales of straw, and 4 gal. of naptha were used to thaw out the ground and provide clay on which the 6-in. slab was poured. The slab was then covered by a tarpaulin and 6 in. or more of horse manure. The air compressor and jackhammer are also used on many excavations of narrow width. For larger excavations, frost breakers consisting of 3-ton metal hammers dropped by dragline or crane do effective work.

3. Snow fences and plows keep roads open, but a small blower attached to the power take-off of a small tractor is a valuable aid around a plant. It throws the snow some 30 or 40 ft. away from the road and leaves the snow adjacent to the roads at the same level as the snow on the level, instead of banked up by the plow.

4. Ice will form or collect on the clarifiers, in the gas seals on the digesters, in the gas lines, in the air vents to pump sumps, in water lines to pumps, and in sludge cars. Heat will cure most of these ills, but when this is not available the scum on the clarifier should be kept to a minimum by keeping down the depth of sludge in the clarifier. Gas lines can be freed of ice by putting an ice-thawing transformer and copper cable to the gas line. Steam from a portable steamer is also useful for gas lines and frozen seal pans. Anti-freeze is only good for a time in keeping seal pans from freezing, as the condensation dilutes it. Salt is used to keep the vent pipe open in the coldest spells of winter at some of the District's small pumping stations. Insulation is generally the cheapest protection for water lines that freeze.

One example of winter troubles is the case history of exposed gas lines on the roof of the four digesters at Winnipeg. These lines were put outside to keep the plant free from the hazards of gas explosions from leaky gas pipes. They were installed with three thicknesses of standard felt insulation. These gas lines froze solid, filled completely with ice. The first winter a portable steam boiler belonging to the city was used to thaw them out whenever they froze. Next, a large copper cable was run from a low-voltage, high-amperage thawing transformer to the gas dome of each digester and this kept the gas lines clear. The insulation was doubled in thickness and special insulation was placed at bends when the thawing

* Presented at Sewage Works Operators' School, University of Minnesota; Minneapolis, Minn.; March 15-17, 1951.

transformer was returned after a year's loan. This still did not free the gas lines of freezing in the coldest weather. The main gas feeder was placed inside the buildings and the feeders of each digester were left on the roof. The heavy insulation, with the larger gas flows in the two primary digesters, gave protection against most weather, but in extremes of −40° F. with strong winds for a protracted period, freezing of thin snow-like webs would cause stoppage of these gas lines. However, a portable steam boiler gave enough heat to free the lines.

The two lines from the secondary digesters continued to give trouble and a trial was made of a heating cable similar to that used in hotbeds. Condensation on the cable or its points of control caused a short circuit, which ignited the felt insulation and a wooden housing filled with flax straw. This produced a spectacular fire on the digester roof in the early morning that was put out by Watch Engineer Schultz, who was well aware of the danger of the gas exploding. Arrangements had been made 10 years before to have the Gas Rescue Squad car of the Winnipeg Fire Department come out when called. A call brought out a standard fire truck and as there are no city fire hydrants at the plant, the firemen were not able to help. These outside gas lines are to be put inside under the digester roof when the plant is extended and this should eliminate these gas line troubles.

5. In a number of secondary sewage pumping stations the condensation on the walls, conduits, and electrical switches and equipment caused many troubles. Installing a 1/4-h.p. motor-driven fan with galvanized air ducts to bring in cold air and take out the moist air resulted in keeping stations dry. The only danger is that of reducing the temperature below freezing. However, by installing thermometers the operators visiting these automatic stations adjust the blowers to do away with condensation without freezing gland water lines.

When condensation makes sleet accumulate on the power lines, short lengths of line can easily be kept clear of ice with a shotgun. This, of course, is not recommended for city practice.

The question of condensation should not be left without relating an experience on the condensate traps and lines collecting the water from the gas lines in cold weather. Inquiries concerning an explosion in a well-known plant elicited advice to check on the condensate lines from gas lines. I was horrified to find that although we had ball float traps, siphons, and condensate lines that looked safe, if a minute piece of dirt got under the ball float, the water would siphon off and the gas would escape. This actually happened while the mechanic and I were checking over one of these drip collectors. This weakness was remedied by putting in double air-breaks and a visible float that would indicate if the line plugged. This precaution has probably saved the Greater Winnipeg Sanitary District thousand of dollars from gas explosion damage.

At this point it might be mentioned that Canadian plants are subjected to two great dangers with which plants in the United States are not troubled. Reference is made to the American consulting engineer and the big American equipment and supply companies, who have grown used to the humid warm-air conditions of the south and who design and produce products unfit for colder climates. This is mentioned only in sadness as a great American sales gift that often gives Canadian plants unnecessary winter troubles.

Advantages of Winter Maintenance

It has been mentioned that winter maintenance may have advantages. Some examples of what is meant are as follows:

1. By using staff that is required to give vacations and holidays, to do main-

tenance that can be carried over until wintertime, more continuity of employment is given.

2. Repairs to sewers and pipes in river beds or near river banks can usually be done more cheaply in the low water of winter.

3. In sections of the plants where painting or insulating cannot be done, due to humidity of the air condensation on the walls, the dry air of the cold spells provides a period when maintenance can be done best and most economically in winter.

4. Inspection of collection sewers and sewer maintenance work can often be done best in winter.

5. An example of the use of wintertime is the repair of the damage done by the summer and fall condensation from a 16,000-gal. water tank, which destroyed the beautiful ceiling of the entrance hall of the main building at the Winnipeg sewage treatment plant. This steel tank rested on five thicknesses of asphalt-impregnated insulating felt. A foot of concrete and an air space also separated the cold tank from the entrance hall ceiling. The felt finally became saturated and moisture got into the concrete. The water supplied to the tank from a deep well was at a constant temperature of 44°F. This cold, on humid days during June, July, August, and September, caused condensation to drip on the plaster and destroy it.

The trouble was finally cured in the dry period of early winter by raising the tank and supporting it on 6-in. H-beams at 2-ft. centers. The space under the tank was filled with rock wool. The outside of the circular tank was insulated with 1-in. thick asbestos blocks held with 1/2-in. galvanized insulating steel tape covered by two coats of asbestos cement and a heavy coat of Ever Jet paint. This vapor seal was extended to the concrete floor and is one of the essentials of the repair. The work eliminated the condensation and permitted the entrance hall ceiling to be restored satisfactorily.

EFFECTS OF CHEMICAL INDUSTRY WASTES—NIAGARA FALLS, N. Y., SEWAGE TREATMENT PLANT

By Edward J. Smith

Superintendent, Sewage Treatment Plant, Niagara Falls, N. Y.

There are very few cities in the United States confronted with the industrial waste problems which exist at Niagara Falls, N. Y.

Situated along the upper Niagara River are many chemical manufacturing industries. These plants are in a position to pump raw water directly from the river for process and cooling purposes. At present they are pumping at a rate of 130 m.g.d., discharging 60 m.g.d. back into the sanitary system.

Not only is the sewage works confronted with the handling of raw water which should be discharged back into the river, but it also is plagued with a large number and quantity of the chemicals available commercially, including halogenated aromatic and aliphatic compounds, synthetic resins, sulfides, chlorine, phosphorus, and the chemicals used in their manufacture.

When the sewage plant was designed, the city realized that facilities must be constructed which would provide in-

* Presented at 1951 Joint Meeting, New York Sewage and Industrial Wastes Assn. and New England Sewage Works Assn.; Springfield, Mass.; June 7–8, 1951.

dustries with an outlet for their unpolluted industrial waste. Therefore, the city designed and constructed intercepting sewers and a diversion sewer to collect industrial cooling and process waters and all chemical waste that could be neutralized and discharged back into the Niagara River without treatment.

Studies made in 1933 showed an average dry weather flow in the existing sewers of 60 m.g.d. This flow included 40 m.g.d. from the industries, of which 30 m.g.d. was unpolluted cooling and process waters and could be discharged directly into the diversion sewer without treatment. The combined sanitary and industrial flow requiring treatment amounted to 30 m.g.d.

Sewer Odors and Explosion Hazard

Of the average 88-m.g.d. flow entering the Niagara Falls sewage treatment plant in 1950, approximately 85 per cent was of industrial origin. The largest portion of this industrial flow is uncontaminated cooling water. However, due to the lack of cooperative effort on the part of most of the local industries in the matter of waste disposal, quantities of industrial organic wastes get into the sewage system to complicate the problem of proper treatment. At times this waste contamination has reached 250,000 p.p.m. in the liquid effluent from one factory. As would be expected, such concentrations of odorous organic chemicals completely mask any odor that might be present from domestic sewage. At times sufficient quantities of volatile and readily combustible organic chemicals have been present to supply the ingredients for an explosion. Only an igniter was needed.

Screening Problem

The Niagara Falls sewage plant is a primary treatment plant, having six fine disc screens with 1/32-in. openings, and is capable of filtering 90 m.g.d. under normal conditions. However, the heavy discharges of resinal products and of various types of plastics and grease-like materials from the industrial plants plug up the fine screens and reduce their capacity to the extent that it sometimes is impossible to filter the entire flow. When this occurs, which is frequently, it is necessary to shut down one screen at a time and knife, scrape, and steam out the openings before placing the screen back in operation.

There are two factors regarding industrial waste that contribute greatly to disrupting normal operation:

1. Chemical wastes that are not soluble in water, and waste having a high chlorine demand.
2. Chemical gases that are physically soluble in water in small percentages, but are readily released by any turbulence.

The turbulence due to the many abrupt drops in level as the sewer system approaches the treatment plant cause dissolved organic vapor to be released from solution. These vapors travel throughout the system independently of the direction of flow of the sewage itself, creating a nuisance to residents throughout the city from the standpoint of odors and causing deterioration of the sewer walls by their corrosive action.

Plant Ventilation

Many of the gaseous chemical materials still present in the influent to the treatment plant are released by numerous drops in level within the plant. Although these drops are kept to a minimum, sufficient quantities of released vapors are usually present to be detectable by odor. At times enough vapor of a lachrymatory nature, usually chlorinated aromatics, is present to cause extreme discomfort among the operating personnel, as well as a serious corrosive action on all exposed metal surfaces. A total plant ventilating capacity of 120,000 c.f.m. is not sufficient to alleviate this condition.

Chlorine and Chlorine Demand

The plant records show a yearly average of free chlorine in the influent to the treatment plant to the extent of 2.5 p.p.m. Free chlorine in the amount of 300 p.p.m. or more occasionally occurs in the influent, 800 p.p.m. being the record concentration to date. On the other hand, there are occasions when the chemicals in the flow exert a chlorine demand. A value between 100 and 200 p.p.m. is not uncommon. The B.O.D. figures, although unusually consistent for such a variable sewage, are, for practical purposes, devoid of any real meaning, as the chemicals in the sewage frequently act as disinfectants. The average B.O.D. is about 54 p.p.m. in the influent and 52 p.p.m. in the effluent.

Color

Highly-colored substances of undetermined origin and not removable by treatment are often present in the plant influent. The consequent color effects on the river directly in front of the plant, which might be pleasing in other circumstances, are extremely disturbing when associated with a sewage treatment plant.

Many conferences were held with local industries in an effort to have them treat or neutralize their wastes before discharge into the sewage system. Little came of these conferences, as no plant would admit discharging objectionable chemical waste into the city sewers.

Sampling Program

In 1949, when the International Joint Commission on Pollution of International Boundary Waters became interested in the Niagara River, the industries started slowly to put their plants in order, or at least began to look into the industrial problem to see where they stood with the International Joint Commission. But because most of them discharge their waste into the city sewer system, they took the attitude that it was the city's problem, not theirs.

The Air Pollution Control Department of the city of Niagara Falls, since its conception in 1947, has applied itself to the task of reducing industrial pollution in the sewers, primarily because, once these organic gases are released from the sewage, the problem becomes an air pollution problem. To accomplish this it was necessary to fix responsibility for pollution on the specific industries. Various techniques for sampling to determine the chemicals in the sewage and the company responsible were tried and discarded. This paper does not mention the specific chemicals collected and identified, because it is felt that the problem is essentially local and its solution would not be hastened by provoking the wrath of the local industries by incriminating them individually before persons unfamiliar with the local situation, but the procedures described would be generally applicable to most organic chemical wastes present in sewage.

Among the sampling techniques tried was the ether extraction of liquid samples at the plant. This did not prove satisfactory because rapid changes in the character of the industrial wastes made it impossible to obtain two samples alike over a necessarily long period of time. It was also an extremely tedious and time-consuming method. In addition, ether is sufficiently soluble in water to make such a technique rather costly, especially in view of the number of extractions that would be necessary.

Finally, the liquefaction of the sewer gases utilizing moderately high pressures and low temperatures was tried. Sewer gases, pulled up through a sampling line in a manhole at the rate of 4 cu. ft. per min., were precooled to remove entrained moisture, metered, compressed at approximately 100 lb. per sq. in. in an electrically-driven compressor, and sent to copper cooling coils packed in dry ice, where they con-

densed and collected. Because of the greater efficiency and the simplicity and directness of this method, in comparison to the other methods attempted, it was selected as the best technique from a practical viewpoint. It also enabled the concentrations of the gases to be more accurately determined. The amount of sample collected using this procedure would vary with the concentration of the gas in the sewers. In Niagara Falls, samples of about 100 c.c. (approximately 0.25 lb.) were collected from 18,000 cu. ft. of sewer gas.

Sample Analysis

Samples thus obtained during 1950 are undergoing examination and analysis. The problems associated with the separation of a complex mixture of organic chemicals having many of the same physical and chemical characteristics are numerous and difficult. Separations by differences in solubilities, boiling points, freezing points, and chemical reactivity have been attempted and all these techniques have been applied separately to parts of the sample in order to facilitate separation.

It has been possible to separate aliphatic and aromatic compounds using acetonitrile as a chemical solvent for the aromatic components. These aromatics have been subjected to fractional distillation. It was found that the ordinary distillation column commonly found in the laboratory was not capable of cleanly separating fractions, even when well-insulated and when using fine heat control. Columns of various length and design, packed and unpacked, and with or without heat supplied to the column itself, were unsuccessful. It was finally decided that heat losses in the column were primarily responsible for the poor operation of the column; to overcome this drawback an elaborate vacuum-jacketed Podbielniak column was purchased. This column has more sensitive heat control on the still-pot through the use of an electric mantle heater and has a thermocouple and potentiometer for measuring the temperature of the take-off vapor.

Some fractions have been separated and identified using this equipment, but there are still many obstructions to analysis of the complete sample. Examples of these difficulties include the formation of azeotropic mixtures and thermal decomposition of some of the sample in which hydrogen chloride from some of the highly chlorinated aromatics splits off, disrupting the distillation and damaging the equipment by its corrosive action.

When these obstructions have been removed and it is possible to pin-point the responsibility for specific wastes, the solution to the Niagara Falls pollution problems will be in the cooperative efforts of the industries and the municipal authorities.

Example of Industrial Cooperation

To illustrate how industrial wastes can be eliminated from the sewage system, the efforts of one large local industry to prevent overloading of the Niagara Falls sewer system are cited. The Electro Metallurgical Company, a division of Union Carbide and Carbon Corporation, is building a complete waste water disposal plant of its own. Now partially in operation, the disposal system collects fluids from Electromet's furnaces, concentrators, and fume- and dust-collecting systems.

These fluids pass through a network of underground lines to pumping stations and a chlorinator located on the plant grounds. The pumping stations force the fluids through an 18-in. pipe line, 5,600 ft. in length, to Electromet's refuse property. Here a Dorr-type thickener makes a separation between the fluids and solids.

The overflow from the thickener is clear treated water, which is routed through a storm sewer to the upper Niagara River. The company uses this storm sewer with the city's permission. The underflow from the thickener, con-

sisting of the solids that were entrapped in the water, is pumped to drying beds located on the refuse property.

After leaving the thickener, the clear water cascades over an aerator—a series of wooden steps. This fall restores the oxygen to the water. Electromet's aerator (or aerating ladder) is modelled after the aerating ladders used by many fish hatcheries. The thickener and aerator are now processing fluids at the rate of 5.5 m.g.d.

Actually, Electromet's waste water disposal system serves a two-fold purpose. It removes the dust and fumes collected in the plant's wet-type dust-collecting equipment and pumps the waste fluids to the refuse property—alleviating pollution of the river that might eventually occur if these fluids were placed in the city sewer system.

The underground system connecting each of the collection points at Electromet to the pumping stations consists of 4,000 ft. of various sized piping 8 in. or larger in diameter. This system is to be added to, on a progressive basis, as other collection points are connected. At present all the waste water from Electromet's three 20,000-kw. carbide furnaces is being collected in the system, as well as the waste water from three 12,000-kw. and four 7,500-kw. ferro-alloy furnaces. In July, 1951, a fourth 20,000-kw. carbide furnace is to be added to the system.

The waste water comes from the scrubbers, which remove the dust from carbide and ferro-alloy manufacturing operations. In years gone by, much of this dust escaped to the open air.

Two pumphouses already have been built on the plant grounds and another is projected. One pumphouse containing two 1,500-g.p.m. pumps is the focal point for collection of waste fluids. It pumps these fluids through a 16-in. pipeline, 3,300 ft. long, to a second pumping station, serving as a booster station for transferring all waste fluids by an 18-in. pipeline to the thickener on the refuse property. Also located at this pumping station is a chlorinator and a pit for the treatment of fluids before they are sent out to the refuse property.

Upon completion of this project, which was started in January, 1947, before the International Joint Commission on River Pollution was set up, the city sewers will be used primarily for sanitary purposes. To date, Electromet's disposal system is the most extensive being undertaken by any Niagara Falls industry to prevent river pollution.

Electromet's engineers have worked with the New York State Health Department, Water Pollution Control Section, on the design and operation of this system, and render periodical reports on its operation. This body has praised the Niagara Falls concern for its efforts and cooperation in alleviating Niagara River pollution.

THE DAILY LOG

Plainfield (N. J.) Joint Meeting

By Andrew Palmer, *Superintendent*

December 1—Discontinued recirculation of final effluent over sprinkling filters for fly control for the winter months. Butterfly valves, motors, and gear reducers were brought to the machine shop for thorough overhaul to be made for spring and summer operation.

December 5—Inspected our 5 mi. of trunk-line sewer and found that boys

had removed one manhole cover and rolled it into a ditch close by. This cover was replaced and a modified C-clamp with double locknut was devised to hold it down. We hope it cannot be removed so easily again, as a heavy wrench will be required to open it.

December 6—Our 1951 budget was approved as submitted last night. It shows an increase in maintenance items over last year. The Joint Meeting complimented the Operating Committee and the superintendent on the business-like manner in which the budget was prepared.

December 10—The last three days have been occupied with work on putting new combs, shearbars, and teeth on the comminutor. This job is done about once every three or four years, depending on the amount of wear shown. The three bottom rows of combs and shearbars were found quite worn and were replaced. After putting the comminutor back in operation, the job was completed by making up a list of replacement parts to order for our stock.

December 12—Regular Friday greasing and oiling program. Careful attention to this detail has saved considerable in the way of headaches and breakdowns.

December 15—Unloaded two carloads of alum, using for the first time an electric hoist designed by our mechanic. This saved considerable amount of lifting of the bags and speeded up the unloading time.

December 19—Overhaul of the No. 1 sludge pump was completed this morning. New bearings were necessary to replace the worn ones. The plunger also was badly worn. After metallizing it with spray steel 80, and grinding down to size, the plunger was put in stock.

The metallizing equipment (for spraying metal on pump plungers, crankshafts, and worn machinery parts), purchased about 10 years ago from the Metallizing Engineering Co., 38–14 30th St., Long Island City, N. Y., more than paid for itself the first year we had it. This equipment should be a standard fixture in all plants where there is a machine shop for doing plant work.

December 22—A general cleaning up and inspection of the pump room and machine shop, combined with a check of the supplies and tools on hand, showed everything in good shape and gave a count for inventory at the same time. It is surprising to note the reduction in temporarily "lost" tools since one man was put in charge of all small tools.

December 24—The annual Christmas party for the men, consisting of a steak dinner with all the trimmings, provided the usual good time for all. Everyone looks forward to this party each year.

December 26—The valve in the end of primary settling tank No. 1 would not open. The threads on the stem were badly worn, so a new stem was inserted and the valve was overhauled.

December 30—Inventory of spare parts on hand was completed after about three days at it. This gave a good opportunity, so orders were placed for pump parts to bring our stock up to par. Operating Committee members visited the plant this afternoon. They were well pleased with the appearance of the plant, also commented favorably on the way our spare parts stock room was kept.

January 5—Painting of the new sludge heater room and pipe gallery between old and new digesters was completed. The time and money expended were well worth-while. This inside work was carried on during a severe cold spell making outside work all but impossible.

Because of the severe conditions encountered, a representative of one of the large paint manufacturers was called in to advise on types, colors, etc. The ceilings were painted with an acid-resisting white enamel, the walls with

beige semi-gloss enamel, and the dado, trim, and windows with "horizon gray" enamel. The concrete floors were painted with "dark stone." All piping was colored the same as adjacent walls or ceiling, with identification striping every 10 ft. Needless to say, this painting really brightens up the pipe gallery and sludge conditioning building.

January 6—A check on the amount of sludge in the eight digesters showed an abundance of sludge to dry, so it was decided to run the spray drier 24 hr. per day for one week to get caught up on the digested sludge. The reason for the accumulation of sludge was the shutdown of the drier over the Christmas and New Year holidays.

January 8—Mechanics checked and overhauled the effluent recirculating mechanism, getting it ready for spring and summer operation.

January 12—Data showed 4,800 cu. ft. of 84 per cent moisture sludge being dried every 24 hr. during the last few days.

January 13—The sludge collector chains in one of the primary settling tanks broke this afternoon. Looked up how long they have been in service and found that they were installed in 1934. After emptying the primary settling tank and cleaning it out, the old chains were cut up and removed. New chain from stock on hand permitted putting the primary tank back in short order.

January 16—The sludge spray drier was put back on normal operation.

January 22—Called the chain manufacturer this morning to get prices and approximate delivery date. Ordered the chain so that our stock would be brought back to where it should be.

January 26—The annual overhaul and painting of the chlorinator at the final settling tank was completed. A test run showed it to be in perfect order for anticipated use.

[Note.—The Plainfield Joint Meeting plant apparently makes good use of inclement winter weather to carry on considerable maintenance on machinery and plant interiors, as suggested in another article in this "Corner."—Ed.]

PHENOL WASTES UPSET DIGESTERS AT HARTFORD, CONN.*

By George Lebetkin

Chemist, Sewage Treatment Plant, Hartford, Conn.

On the evening shift of January 1, 1951, creosote-phenolic odors were noted by the night shift operator in the rack house at the Hartford, Conn., sewage treatment plant. There was no unusual appearance upon the sewage surface and these odors were dismissed as one of many connected with sewage treatment. On February 1, around 3:30 P.M. when seven hourly raw sludge samples were composited, it was noted that each sample had the typical odor of creosote-phenolic tars connected with usual gas company wastes. Also, each sample had a liberal amount of darkish, oil-like material, which had slowly streaked up to the surface. These two observations coincided with experience of some years ago, when similar occurrences had happened for which the local gas company had then admitted responsibility.

As soon as these wastes were noted,

* Presented at 1951 Joint Meeting, New York Sewage and Industrial Wastes Assn. and New England Sewage Works Assn.; Springfield, Mass.; June 7–8, 1951. The material was taken from a report in the industrial waste file of the Bureau of Public Works, Hartford (Conn.) Metropolitan District, dated February 13, 1951.

the local gas company was informed. On February 2, that company stated that possibly some waste tars from one of the scrubbers which was being cleaned may have passed into the sewer for 20 min., if at all. This scrubber cleaning was a non-routine operation.

On February 2 and 3, every hourly raw sludge sample contained diminishing amounts—all, however, in significant concentration—of this waste. This could be called residual waste present in the sewers and sedimentation tanks. What is most important, however, is that from February 2 onward, each hourly digested sludge sample from the digestion tanks contained phenolic odors. On February 13, these odors still continued from the digesters. Even after the digested sludge was elutriated, some phenolic odor persisted and was also present in the filter cake.

On February 6, tests showed that gas plant wastes had permeated throughout all four digesters. Beginning February 2, digester gas began to diminish, slowly at first, as shown by the following:

Date	Gas Production (cu. ft.)
Feb. 2	89,700
Feb. 3	88,600
Feb. 4	71,600
Feb. 5	68,500
Feb. 6	68,000
Feb. 7	57,800
Feb. 8	47,200
Feb. 9	25,460

Due to the ground-water infiltration and poor suspended solids removal of this period, the raw sludge poundage pumped daily was low.

By February 6, the alkalinity and pH of the tank contents had dropped, a condition due to inactivation of digestive agent by the wastes. On February 12, the drop was unabated and corrective measures were instituted requiring extra personnel and equipment.

As gas production dropped, oil consumption for heating the digesters and the plant buildings increased (each cubic foot of gas has a heating value of approximately 575 B.t.u.) As gas production dropped, the gas boiler controls became difficult to adjust and at least three full man-days were required for this emergency work—all in the early morning hours. Each time, before the adjustments were made, all heat to the digesters and buildings was lost for periods up to as much as 9 hr. in subzero weather. To compound the situation, water got into the fuel oil tank. Until this condition was remedied the digesters went for a further period without heat.

By the time the heavier sludge at the digester bottoms containing most of the phenol had been drawn out and the heating problem straightened out, gas production started to come back in part. Then the spring freshet season fortunately arrived, shutting down the plant for this yearly period. (When the Connecticut River is at elevation 8 ft. or higher, the plant is by-passed. This condition pertains during an annual average two-month period.)

In all fairness, it should be pointed out that the digestive health of the digesters was poor to begin with this season, due to diminishing heat transfer efficiency and to questionable digester capacity. If the digestive condition were at an average level, the tanks might have thrown off the phenolic poisoning effects with only a partial drop in gas production occurring, as in some cases in past plant history. Incidentally, it should be noted that the phenolic wastes cleaned out the main sludge line to the digesters and the raw sludge pressure dropped considerably.

TIPS AND QUIPS

First Atomic Age Department Store

At last the celebrated but difficult to obtain Geiger counter can be purchased as easily, and about as cheaply, as a wrist watch. This is made possible by the opening during September of the first retail shop for radioactive detectors at, of all places, the world's busiest corner—Fifth Avenue and 42nd Street, New York City.

No longer confined to the bulky laboratory-type Geiger counter, the new instruments include a score of portable streamlined detector types for various specific uses, such as prospecting, education, civil defense, research, and hobbyists. Some idea of the broad field covered by the manufacturers, The Radiac Company, is given by the catchy names assigned the various types. The names?—Sniffer, Super-Sniffer, Snooper, Ferret, Classmaster, Cutie Pie, Civion, Zeuto, and Professional!

Insecticide Paint Additive

A new "mix-with-paint" insecticide employs an entirely new scientific approach to the universal problem of insect control. It virtually paints insects away in one application, for the life of the paint—normally 4 years. The material is claimed to be easily and uniformly mixed with all types of interior and exterior paints, including oil, water, and dry paints, as well as whitewash, casein, dement, and stucco paints. Also, to bring certain death to all flying, crawling, chewing, and sucking insects, yet be completely odorless and non-toxic to humans and household pets.

Addition of the insecticide, according to the Dianol Sales Corp., Allentown, Pa., does not change the normal characteristics of the paint and does not affect the color. Like the pigment, Dianol does not dissolve, but is suspended in the paint. This permanent residual quality remains active throughout the entire thickness of the paint film, as well as on the surface, and means certain death for all insects after contact. Death occurs within 15 min. to a few hours, depending on the insect. The material is available in ¼-lb. and 1-lb. cans, as well as in bulk for quantity requirements.

Air-Borne Foam

Although no barbershop tenors were heard to sing "it floats through the air

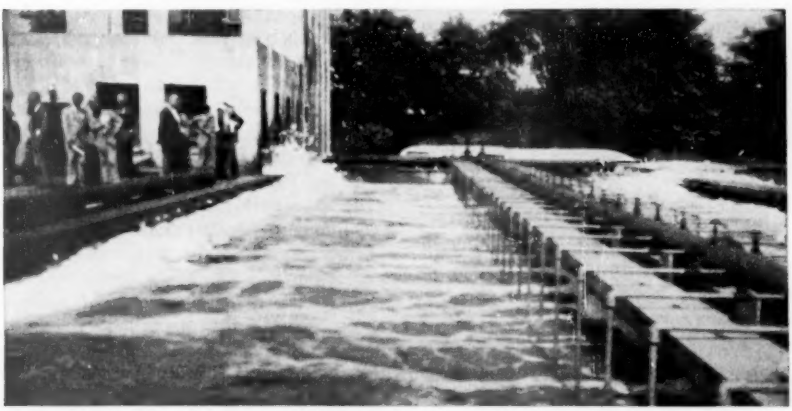


FIGURE 1.—Froth on aeration tanks is whipped into air by light gusts of wind.

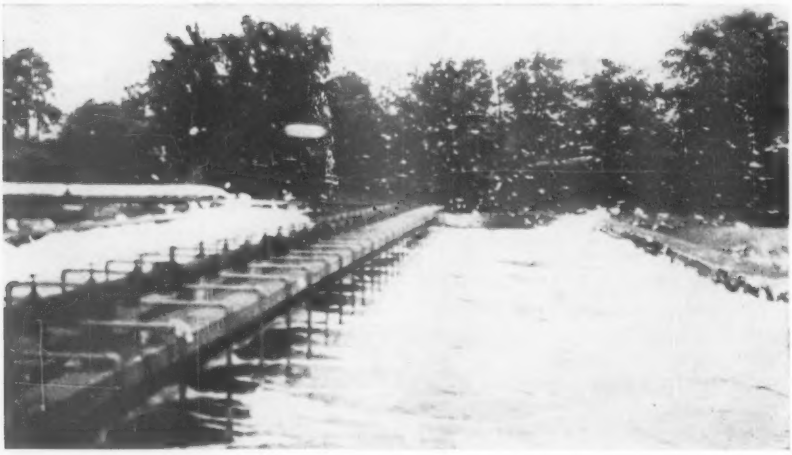


FIGURE 2.—Heavier gusts carry froth (white blots) as much as 150 ft. from tanks.

with the greatest of ease," that might well have been the theme of the setting depicted in Figures 1 and 2. The occasion was an inspection trip to the Etobicoke Township sewage treatment plant, near Toronto, Ont., during the 1951 Annual Meeting of the Canadian Institute on Sewage and Sanitation, held in Toronto, August 20–22, 1951.

The froth on the activated sludge aeration tanks was of considerable interest, but the main feature was provided by a cooperative Nature when gusts of wind carried large gobs of the foam up to 150 ft. from the tanks. Pictorial evidence of this phenomenon was provided by René Cyr, assistant chief engineer, Dominion Ministry of Health, who took the pictures. Some idea of the size and flight pattern of the frothy "covey" is given by the white spots against the background foliage.

"Disconcerted" would be a mild term for the attitude felt by operators who had to work on the leeward side of these tanks at a time like this, as was evidenced by the visitor who was hit on the back of the head by a large chunk of the "head" as he boarded the bus for the return trip!

Cheap Absorbent

Although "Missouri meerschaum" pipes and the old-style farm sanitary conveniences provided some small outlet for their use, corncobs have generally been considered a waste product. In recent years, however, research has found industrial use for some 200,000 tons of cobs per year and is daily finding new applications.

In addition to use for the manufacture of the important chemical furfural, cobs are ground for use in soft grit blasting, abrasive cleaning, polishing metals and glass, and a variety of other applications. Latest developments indicate that cobs may well replace corn meal as an abrasive in powdered skin cleansers, as well as in cake and paste soaps.

It is the absorbent properties of ground corncobs, together with their organic content, that should make them of interest to sewage works personnel, particularly in the areas where corn is a major farm product. The manufacturer of one ground corncob product claims that 1 lb. will absorb approximately 3.75 lb. of water, but that the cob particles have a low water-solubles content.

This opens the possibility of using finely ground cob as an admixture to help condition sludge, hasten its drying, and make it more suitable for fertilizer use, in line with the experimental work on sawdust reported by Ullrich and Smith (THIS JOURNAL, **22**, 4, 567; Apr., 1950).

Trees Anticipate Longer Life

City trees may soon be enjoying longer and healthier lives. According to the American Public Works Association, the answer to growing trees successfully in areas covered with pavement is not a new wonder drug, but a new type of porous asphalt being tried out in Providence, R. I. It is hoped this type of asphalt will prove to be a covering that will withstand foot traffic and still allow ample water to get through to the roots of the trees.

The experiments deal with trees planted in the paved pedestrian islands of a parking area in Providence. The new porous asphalt being used as paving allows 80 per cent of the rainfall to percolate into the ground over the whole surface of the island walks. This binder-course mixture of stone and sand combined with asphalt, obtained after considerable testing, allows 500 cc. of water to go through a 5-in. ring of the mixture in 8.5 sec. The percolation is equivalent to a rainfall of nearly 15 in.

The pedestrian islands which house the trees are "dished" to retain water. Recently, when hoses were turned on them, not a drop of water ran over the curbs because it was absorbed as fast as it streamed onto the surface of the asphalt.

Few cities have had success in planting and growing trees in paved areas, because they cannot provide adequate open ground around the bases of the trees. Watering just around the trunk is not enough to provide the necessary moisture for the tree's fingerling ends. It is hoped this new paving plan will get to the root of the problem by providing for pedestrian traffic as well as insuring adequate moisture for the trees.

This brings up the interesting possibilities of reduced stormwater runoff and less root troubles in sewers if the trees can get the moisture they need from surface sources rather than buried pipes.

Anti-Rust Paint

A new penetrating and sealing antirust paint that can be applied over rusted surfaces has been announced. Claimed to be suitable for both interior and exterior use, the new paint is reputed to be equally effective in preventing rust on new metal or stopping rust action on presently rusted metal.

The manufacturer, Paint Corporation of America, Fidelity Building, Cleveland 14, Ohio, advises that its PCA–100 can be applied right over rust without extensive surface preparation such as wire brushing, scraping, or sandblasting. Upon application the paint penetrates through the rust layer into the base metal and seals the surface against further rusting. It is suitable for either brush or spray application.

PCA–100 is furnished in black only. Due to its penetrating characteristics, the manufacturer recommends it for use solely as a "finish" coat. A companion product, PCA–101, is a clear paint equally effective for rust prevention and can be painted over with any standard paint of any color.

The Ever Faithful Few

Program and attendance committee chairmen of the Federation's member associations will no doubt appreciate the feelings entertained by the author of the following, gleaned from the June, 1951, issue of *Public Health* (South Africa):

When the meeting's called to order
And you look around the room
You're sure to see a chap or two
From out the shadows gloom,
Who are always at the meeting,
And who stay to see it through,
Whom you can always count on;
The Ever Faithful Few.

They fill the thankless office,
They're always on the spot,
No matter what the evening's like;
Be the weather fine or not.
They're not fair-weather members,
They're tried and they are true,
The Chaps we can rely on;
The Ever Faithful Few.

There's a lot of other fellows
Who come when in the mood,
When everything's convenient,
And if they're feeling good;
They're a factor in the Association,
And necessary, too,
But the ones who never fail us
Are the Ever Faithful Few.

Took Brass to Take Brass

Apparently the temptation of so much brass was too much for someone with an eye for a black market Mark in metal-short Germany. At least that would appear to be the explanation for a couple of entries in the 1950 annual report of the Wupperverband, translated as follows:

Remscheid-Lobach Plant

A large part of the brass distributor nozzles on the filter beds was stolen in October 1950. During the winter of 1950–51 these brass nozzles had to be replaced with newly fabricated ones . . . .

Remscheid-Mühlenteich Plant

At this plant, also in October 1950, a large number of brass nozzles was stolen, which had to be replaced with newly fabricated ones . . . .

Incidentally, have you checked your own nozzle field since last night?

DON'T BE A "CUT-OFF"

Several hundred good readers of THIS JOURNAL will have their names removed from the mailing list after they receive the January issue, just because they will have been a bit tardy about remitting 1952 dues. Nearly all will be reinstated before 1952 is over, to be sure, but there are at least two good reasons why they should maintain their memberships without interruption, to wit:

1. Supplies of some back numbers may be exhausted before they are reinstated, so that a complete file for the year cannot be furnished.

2. Extra work is required by the Member Association secretary, by Federation headquarters, and by the mailing list clerks at the printing plant, with chances for errors to be made in each place.

To avoid being a "cut-off" is simple. Just remit your dues to your Member Association secretary as soon as you receive your 1952 dues notice from him—and if you receive no notice, send your dues to him anyway, without further delay!

Reviews and Abstracts*

Rivers Department, City of Manchester, England, Report for the Two Years ended March 31, 1950. 38 pp.; tables.

This report covers the activities of the Rivers Department, which served about 874,000 population in 1950. The bulk of the sewage is treated at Davyhulme. The liquid sludge is carried to sea, where a depth of 15 fathoms (90 ft.) is available. The total flow of sewage ranges from 54.399 to 55.223 m.g.d. (Imp.), including 5.411 m.g.d. (Imp.) of industrial wastes. Between 1,780 and 2,006 trade effluents are examined yearly. The raw sewage contains from 240 to 255 p.p.m. of B.O.D. and 156 to 161 p.p.m. of suspended solids. About 11 per cent of the annual flow is treated in storm-water tanks, the balance being settled and treated by contact beds or activated sludge up to their present capacity. Three types of activated sludge plants are operated (bio-aeration, simplex aerators, and diffused air). A new type of diffuser is under test, of dome shape. The results are summarized as follows for the activated sludge plants:

Average Results for Two Years Ended March 31, 1951

	Bio-Aeration		Simplex		Diffused Air	
	1949	1950	1949	1950	1949	1950
Flow (g.p.d., Imp.)	620,000	678,000	1,159,000	1,057,000	20,582,000	21,378,000
Detention (hr.)	17.8	16.3	13.8	15.1	11	11
Power (hp./m.g.)	45.1	37.3	26.4	27.5	32.8	35.3
Effluent:						
Ammonia N (p.p.m.)	22.9	23.1	22.6	23.4	22.3	22·7
Albumin N (p.p.m.)	1.9	2.3	2.1	2.5	2.2	2.1
Nitric N (p.p.m.)	1.1	1.3	1.2	1.3	1.1	1.1
Chlorides (p.p.m.)	271	321	268	326	254	297
B.O.D. (p.p.m.)	17.6	22.8	18.1	26.1	20.8	19.7
Susp. solids (p.p.m.)	19.0	28.0	20	25	22	25
B.O.D. red. (%)	87.8	85.9	87.5	83.8	85.6	87.8

The activated sludge plants have been in use for 15 years.

The composition of the entire plant effluent at Davyhulme in the two years averaged 49.9 p.p.m. of B.O.D. and 32 p.p.m. of suspended solids.

In 1948–1949, 306,573 tons of sludge were removed for disposal; in 1949–1950, sludge removal totaled 290,000 tons, of which the major portion was carried to sea.

Detritus is dumped on land and covered with soil.

The excess activated sludge is disposed of variously—in part to primary settling tanks; in part, after thickening and concentration, to sludge digestion tanks or lagoons. Only a small part is sent to sea after thickening. Sludge digestion deals with 120,000 tons per year of mixed sludge, with heat for 11 to 12 days. Lagoons occupy 11.5 acres, with a maximum capacity of 95,000 tons. Since March, 1941, about 363,000 tons of sludge have been handled.

The sewage of some 47,000 people is treated by the activated sludge process at Withington, producing a somewhat better effluent than at Davyhulme.

The report also contains an Appendix (No. III) on "The Availability of Nitrates in Sewage Effluents," by C. Jepson and G. Greene. The authors discuss various claims as to the value of nitrates in an effluent and a stream and conclude that

* Please send to Federation headquarters all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in THIS JOURNAL. Publications of public health departments, stream pollution control agencies, research organizations, and education institutions are particularly desired. Address such material: Federation of Sewage and Industrial Wastes Assns., 325 Illinois Bldg., Champaign, Ill.

the value of nitrate oxygen to a receiving stream depends on the condition of the stream. If it is reasonably pure, the nitrates are of no value as long as dissolved oxygen is present. If the stream is denuded of dissolved oxygen, nitrates may be helpful. Experiments are described on (1) the availability of nitrates, (2) an incubation test, and (3) biochemical oxygen demand. The use of a nitrified effluent as a diluent has improved the performance of a bio-aeration unit. The authors conclude that although oxidized nitrogen is a potential source of oxygen, the latter does not become available for biological life until all the free dissolved oxygen has disappeared. Given an adequate retention period during which any dissolved oxygen present is exhausted, settled sewage may be improved in quality by the reduction of oxidized nitrogen present in a filter effluent used as a diluent.

LANGDON PEARSE

Sea-Water Intrusion into Ground-Water Basins Bordering the California Coast and Inland Bays. Water Poll. Investigations Rep. No. 1, California Dept. of Pub. Works, Div. of Water Res. Mimeo., 23 pp. and 6 tables (Dec., 1950).

Salt water from the ocean has polluted approximately 90,000 acres of fresh-water bearing deposits in 13 major and minor ground-water basins of the California coast and inland bay areas, and threatens 7 other ground-water basins. Continued pumping of fresh water in these areas at present rates will allow further encroachment of salt water, resulting in widespread deterioration of fresh ground-water supplies. The most serious invasion to date is in the overdrawn West Basin, in Los Angeles County, and the Central Coastal Basin, in Orange County.

Possible methods of control include:

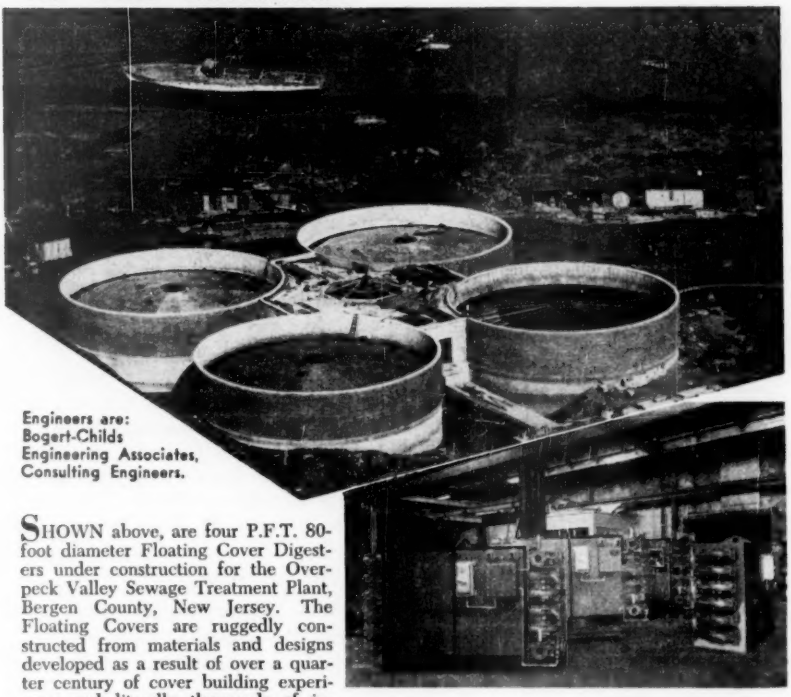
1. Raising ground-water levels to or above sea level by reduction or rearrangement of pattern of pumping draft.
2. Direct recharge of overdrawn aquifers to maintain ground-water levels at or above sea level.
3. Maintenance of a fresh-water ridge above sea level along the coast.
4. Development of a pumping trough adjacent to the coast.
5. Construction of artificial subsurface dikes.

Under the present law, no administrative agency of the state is empowered to take all necessary steps to correct or prevent sea-water intrusion. Remedial legislation has been suggested.

[Note by abstractor—The general problem was considered by the Burr-Hering-Freeman Report on Additional Water Supply for New York City, Nov. 30, 1903 (pp. 390–428), in connection with wells along the south shore of Long Island, in a part of the Brooklyn, N. Y., water supply system.]

LANGDON PEARSE

PICTURE OF EFFICIENT, DEPENDABLE, CONTROLLED DIGESTION IN THE MAKING



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These digesters with four P.F.T. No. 423 Heat Exchangers, P.F.T. Selectors and Gauges and P.F.T. Gas Safety Equipment will provide the ultimate in a Controlled Digestion System with built-in flexibility for present and future needs.

Each of the P.F.T. No. 423 Heat Exchangers, shown at right, has a rated sludge heating output of 873,000 B.t.u. per hour and is provided with automatic controls to maintain within 1 degree the temperature of one of the digesters by circulating the digester contents through the Heat Exchanger. Waste heat from the sludge gas engines is utilized by circulating the engine jacket cooling water through the Heat Exchangers.

Here again P.F.T. equipment based upon P.F.T. experience gained in developing this modern method of external sludge heating and hundreds of successfully operating installations assures efficient and dependable operation.

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Proceedings of Member Associations

GEORGIA WATER AND SEWAGE ASSOCIATION

The 1951 Annual Meeting of the Georgia Water and Sewage Association was held in connection with the 20th Annual Georgia Water and Sewage School at the Georgia Institute of Technology, Atlanta, Ga., September 19–21, 1951. A total of 302 persons were registered for the school.

Following an address of welcome by Blake R. Van Leer, president, Georgia Institute of Technology, papers and demonstrations were given on September 19 as follows:

"Water and Sewage Plant Housekeeping," by Paul Weir, general manager, Atlanta Water Works.

"Elements of Water and Sewage Hydraulics," by R. E. Stiemke, Georgia Institute of Technology, Atlanta.

"Chlorination of Water and Sewage," by Harry A. Faber, research chemist, The Chlorine Institute, New York, N. Y.

"Selection, Operation and Maintenance of Pumps," by John R. Purser, Jr., president, Purser and London, Inc., Charlotte, N. C.

"Quality Protection of Georgia Streams," by W. H. Weir, Georgia Department of Public Health.

The session ended with a demonstration of sewer cleaning by rod machine, by R. W. Thomson, Roto-Rooter Service, Atlanta.

The morning session on September 20 included papers as follows:

"Differentiating Chlorine Compounds," by R. S. Ingols, research professor, Georgia Institute of Technology, and A. T. Storey, chemist, Atlanta Water Works.

"Cathodic Protection," by A. T. Storey.

"Bacteriology of Water and Sewage," by H. A. Wyckoff, Georgia Institute of Technology.

"Chemistry of Water and Sewage," by H. B. Friedman, Zep Manufacturing Corp., Atlanta.

"Sterilization of Mains, Tanks and Wells," by Sherman Russell, superintendent of filtration, Atlanta Water Works, and John M. David, Layne-Atlantic Co., Albany.

This was followed by an inspection tour of chlorine and ammonia cylinder filling equipment of Tesco Chemical, Inc., Atlanta, where a buffet lunch was also enjoyed.

The afternoon of September 20 was devoted to an inspection of the Atlanta water purification plant and the new Construction Division building.

On September 21 concurrent sessions for advanced, basic, ground water, and sewage sections were held. Papers and demonstrations at these sessions included:

"Radioactive Materials and Their Effect on Environmental Health," by Conrad P. Straub, sanitary engineer, U.S.P.H.S., Oak Ridge National Laboratory.

"Water Treatment Units," by Richard H. King, Georgia Institute of Technology.

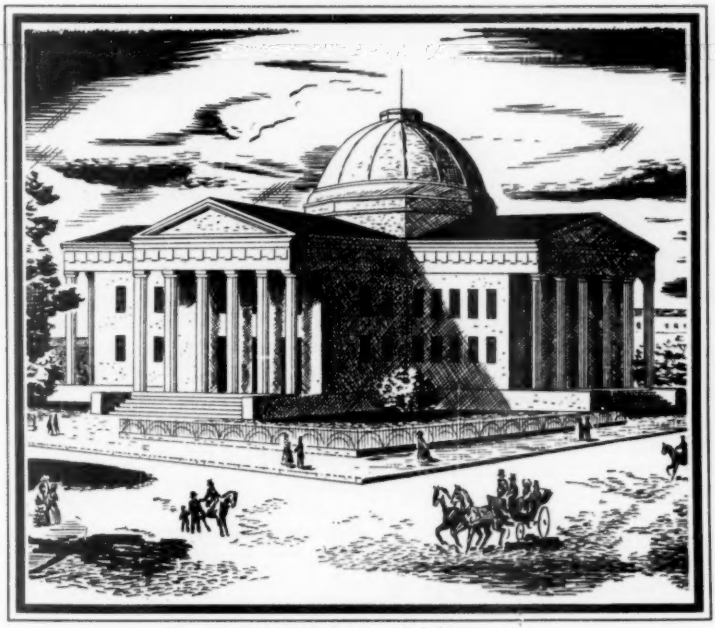
"Coagulation Tests," by N. M. deJarnette, Georgia Department of Public Health.

"Plant Control Tests," by E. McEntire and N. M. deJarnette, Georgia Department of Health, and A. T. Storey, chemist, Atlanta Water Works.

"Relationship of Geology to Water Wells in Georgia," by S. M. Herrick, Georgia Department of Geology.

"Construction and Operation of Wells," by John L. Snow, Layne-

(Continued on page 486a)



The old courthouse in St. Louis as it looked 100 years ago

St. Louis, Missouri has a cast iron water main in service that was installed more than 100 years ago. That is not surprising as St. Louis is one of our oldest cities, founded by the French and taken over by the U.S.A. with the Louisiana Purchase. Yet this old main is still withstanding the traffic shock and beam stresses imposed by multi-ton trucks and congested underground utility services in a great manufacturing city. More than thirty other American cities have cast iron water and gas mains in service that were installed over a century ago—indisputable testimony to the strength factors of long life inherent in cast iron pipe.

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"Quality of Ground Water," by N. M. deJarnette.

"Introduction to Sewage Treatment,," by R. E. Stiemke.

"Operation of Imhoff Tanks," by W. B. Williams, Georgia Department of Health.

"Mechanical Clarifiers," by R. E. Fuhrman, superintendent, District of Columbia sewage treatment plant.

"Sludge Digesters," by R. S. Ingols.

"Detecting Distribution System Leaks," by W. D. Hudson, The Pitometer Co., New York, N. Y.

"Trickling Filters," by Richard H. King, Georgia Institute of Technology.

"Miscellaneous Sewage Plant Units," by C. E. Drummond, Weideman and Singleton, Atlanta.

"Effects of Industrial Wastes on Sewage Treatment," by Harold R. Murdock, chemical engineer, Robert & Co., Atlanta.

"Panel Discussion—Improving Taste and Odor of Ground and Surface Waters," by R. S. Ingols, H. A. Faber, T. A. Jones, A. T. Storey, and F. M. Hull.

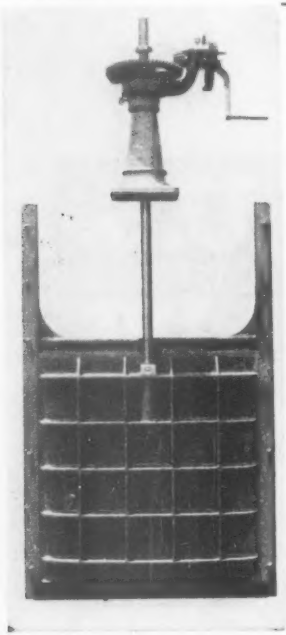
Examinations for operators' certificates were held at the close of the technical sessions.

The conference closed with the Annual Association Banquet and Business Meeting, at which the dinner was furnished through the courtesy of the Southern States Chemical Co., Atlanta.

Officers elected to serve during 1951–52 were:

President: V. D. Parrott, Jr., Dalton.
1st Vice-President: L. C. Bowen.
2nd Vice-President: S. Russell, Atlanta.
Secretary-Treasurer: A. T. Storey.
Asst. Secretary-Treasurer: I. C. Kelley.

A. T. STOREY,
Secretary-Treasurer



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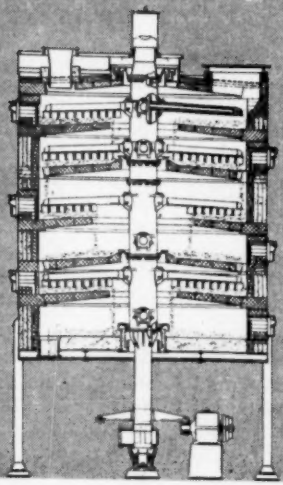
3. Lower labor costs through mechanical stoking.
4. Elimination of odor and fly ash nuisance.
5. Compact, attractive plant design.

Nichols Engineers are always ready to assist in solving municipal and industrial sewage sludge disposal problems.



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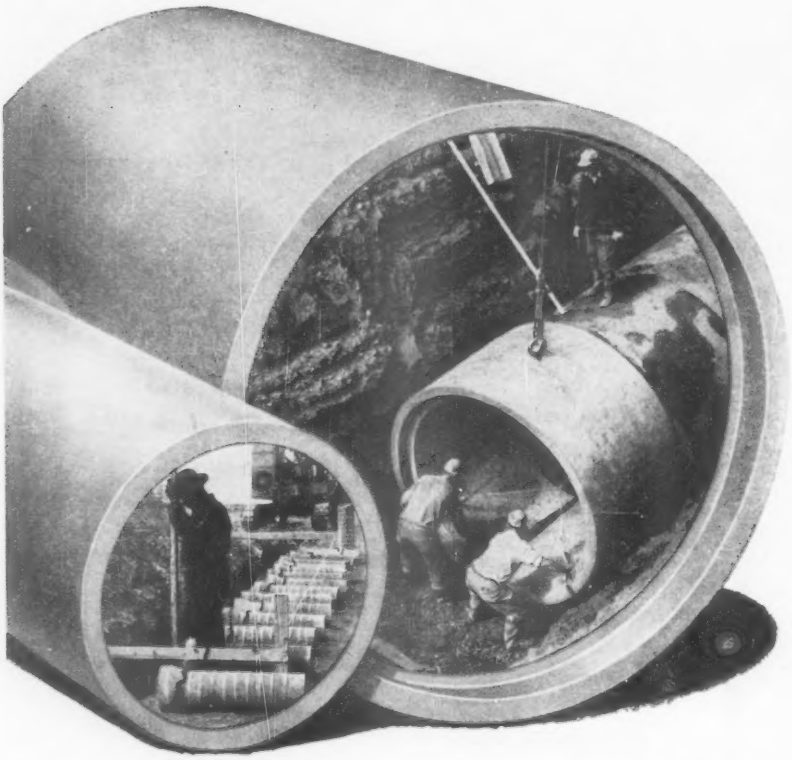

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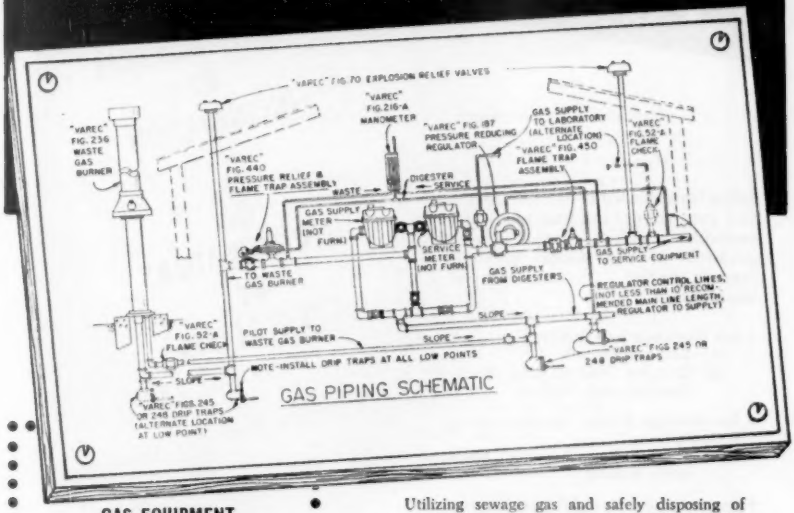
"VAREC" FIG. 70 EXPLOSION RELIEF VALVES
"VAREC" FIG. 236 WASTE GAS BURNER
"VAREC" FIG. 216-A MANOMETER
"VAREC" FIG. 197 PRESSURE REDUCING REGULATOR
GAS SUPPLY TO LABORATORY (ALTERNATE LOCATION)
"VAREC" FIG. 450 FLAME TRAP ASSEMBLY
"VAREC" FIG. 52-A-1 FLAME CHECK
"VAREC" FIG. 440 PRESSURE RELIEF & FLAME TRAP ASSEMBLY
WASTE
DIGESTER SERVICE
GAS SUPPLY METER (NOT FURN.)
SERVICE METER (NOT FURN.)
GAS SUPPLY FROM DIGESTERS
GAS SUPPLY TO SERVICE EQUIPMENT
REGULATOR CONTROL LINES (NOT LESS THAN 10' RECOMMENDED MAIN LINE LENGTH, REGULATOR TO SUPPLY)
TO WASTE GAS BURNER
"VAREC" FIG. 52-A FLAME CHECK
PILOT SUPPLY TO WASTE GAS BURNER
SLOPE
"VAREC" FIGS 245 OR 248 DRIP TRAPS
NOTE-INSTALL DRIP TRAPS AT ALL LOW POINTS
"VAREC" FIGS. 245 OR 248 DRIP TRAPS (ALTERNATE LOCATION AT LOW POINT)
GAS PIPING SCHEMATIC

GAS EQUIPMENT SPECIFICATIONS

a. **PRESSURE RELIEF AND FLAME TRAP ASSEMBLY**
"VAREC" Fig. No. 440

b. **FLAME TRAP ASSEMBLY**
"VAREC" Fig. No. 450

c. **FLAME CHECK**
"VAREC" Fig. No. 52A

d. **EXPLOSION RELIEF VALVES**
"VAREC" Fig. No. 70-1

e. **WASTE GAS BURNER**
"VAREC" Fig. No. 236

f. **DRIP TRAPS**
"VAREC" Fig. No. 245 (automatic)
"VAREC" Fig. No. 248 (hand operated)

g. **MANOMETERS**
"VAREC" Fig. No. 216A

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Utilizing sewage gas and safely disposing of excess gas is an automatic operation with "VAREC" Equipment incorporated into your sewage plant design. With this equipment, accurate gas pressures are maintained in all service lines. As soon as the digesters make more gas than required for service, the pressure relief valve to the waste gas burner opens to permit safe burning of the excess.

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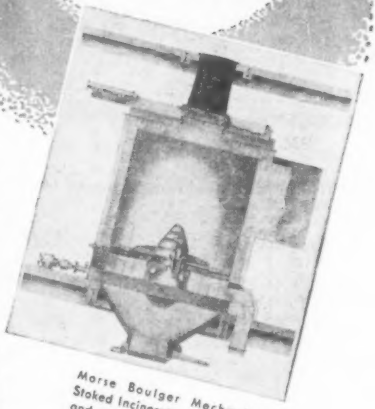

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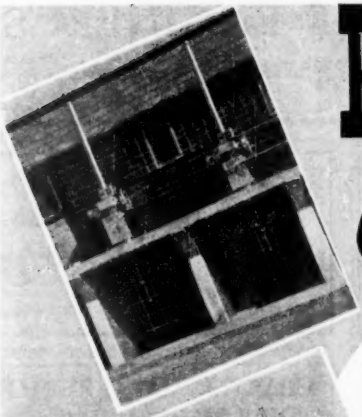

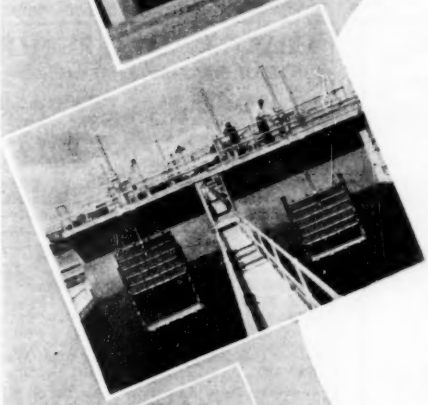

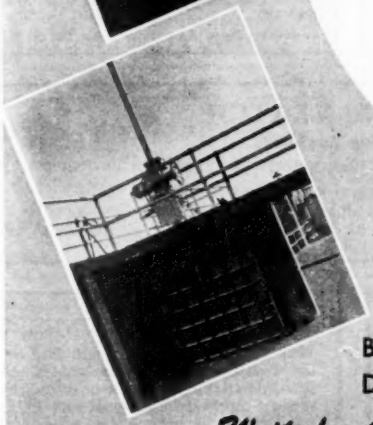

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INDEX TO ADVERTISERS

	Page
Ace Pipe Cleaning Contractors, Inc.	471a
American Brass Company	470a
Bailey Meter Company	456a
Builders-Providence, Inc.	463a
Cast Iron Pipe Research Association	430a
Chicago Pump Company	461a
Combustion Engineering-Superheater, Inc. (Flash Dryer Div.)	472a
Dorr Company, The	427a
Fairbanks, Morse & Company	466a
Flexible Sewer-Rod Equipment Company	468a
General American Transportation Corporation	479a
General Chemical Division (Allied Chemical & Dye Corp.)	474a
Inertol Company, Inc.	477a
Infilco Incorporated	475a
Link-Belt Company	469a
Morse Boulger Destructor Company	490a
Morse Bros. Machinery Company (Fuhrai Gas Division)	491a
Nichols Engineering and Research Corporation	467a
Pacific Flush Tank Company	463a
Portland Cement Association	468a
Rockwell Manufacturing Company (Nordstrom Valve Division)	473a
Simplex Valve and Meter Company	465a
Snow Irrigation Supply Company	484a
U. S. Pipe and Foundry Company	485a
Vapor Recovery Systems Company	489a
Wallace and Tiernan Company, Inc.	Back Cover
Worthington Pump and Machinery Corporation (Public Works Div.)	472a
Yeomans Brothers Company	462a

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